BRITISH WELDING JOURNAL

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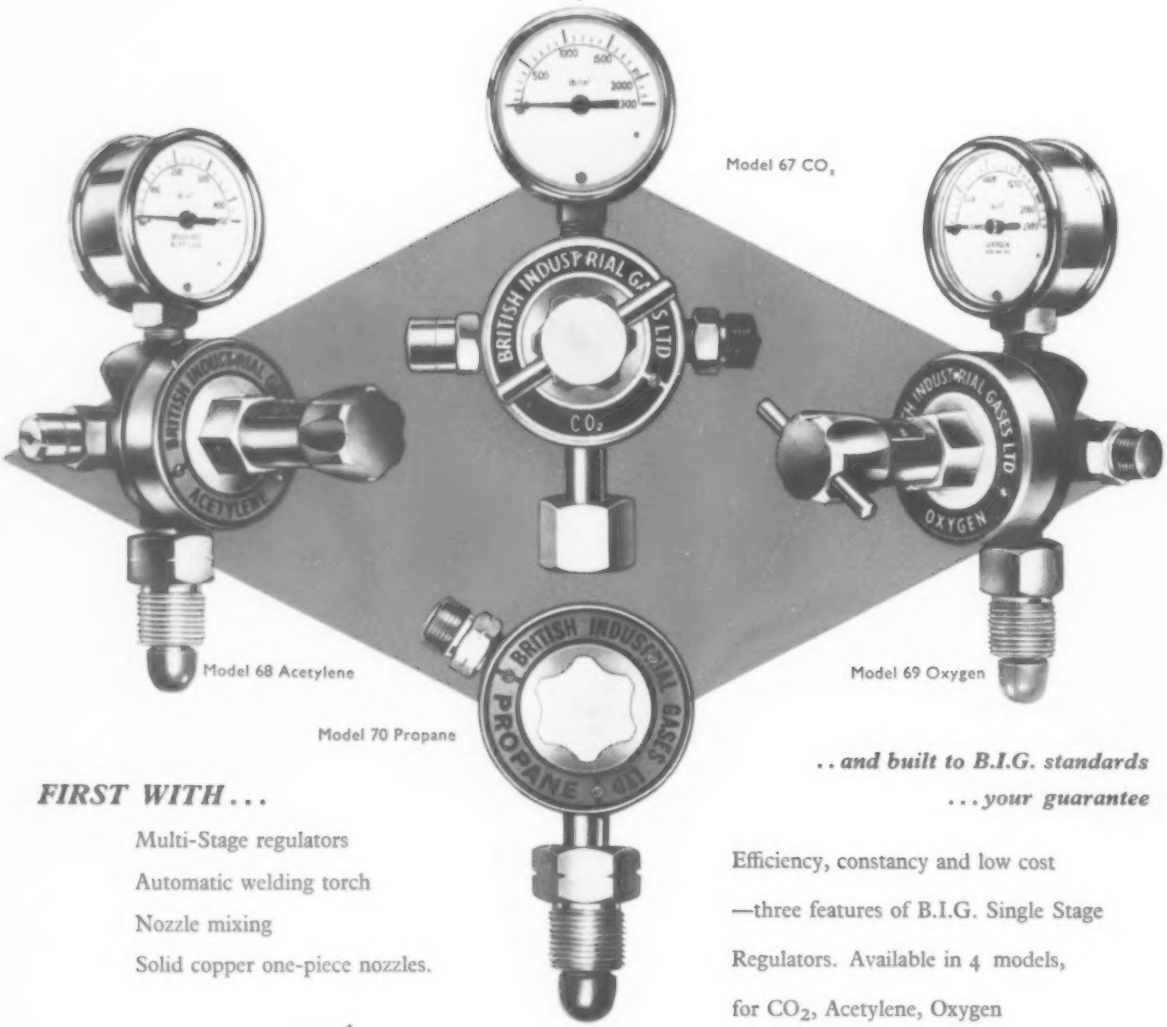

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Model 68 Acetylene

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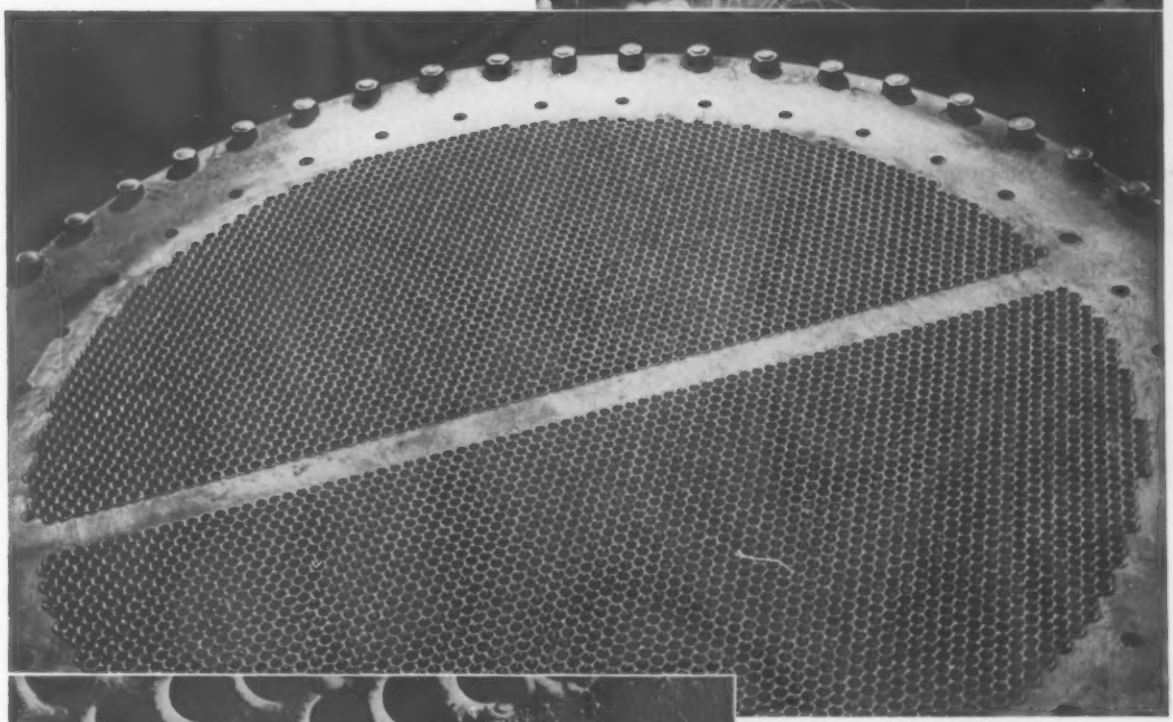
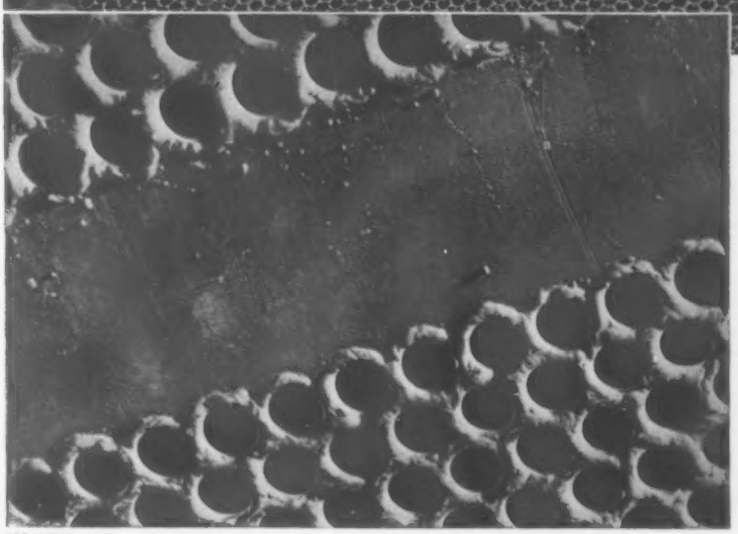
Inside front cover

Dexterity in WELDING





Tube plate for a Heat Exchanger, incorporating 5,518 tubes ¾ in. dia., and involving 1,078 footage of welding.

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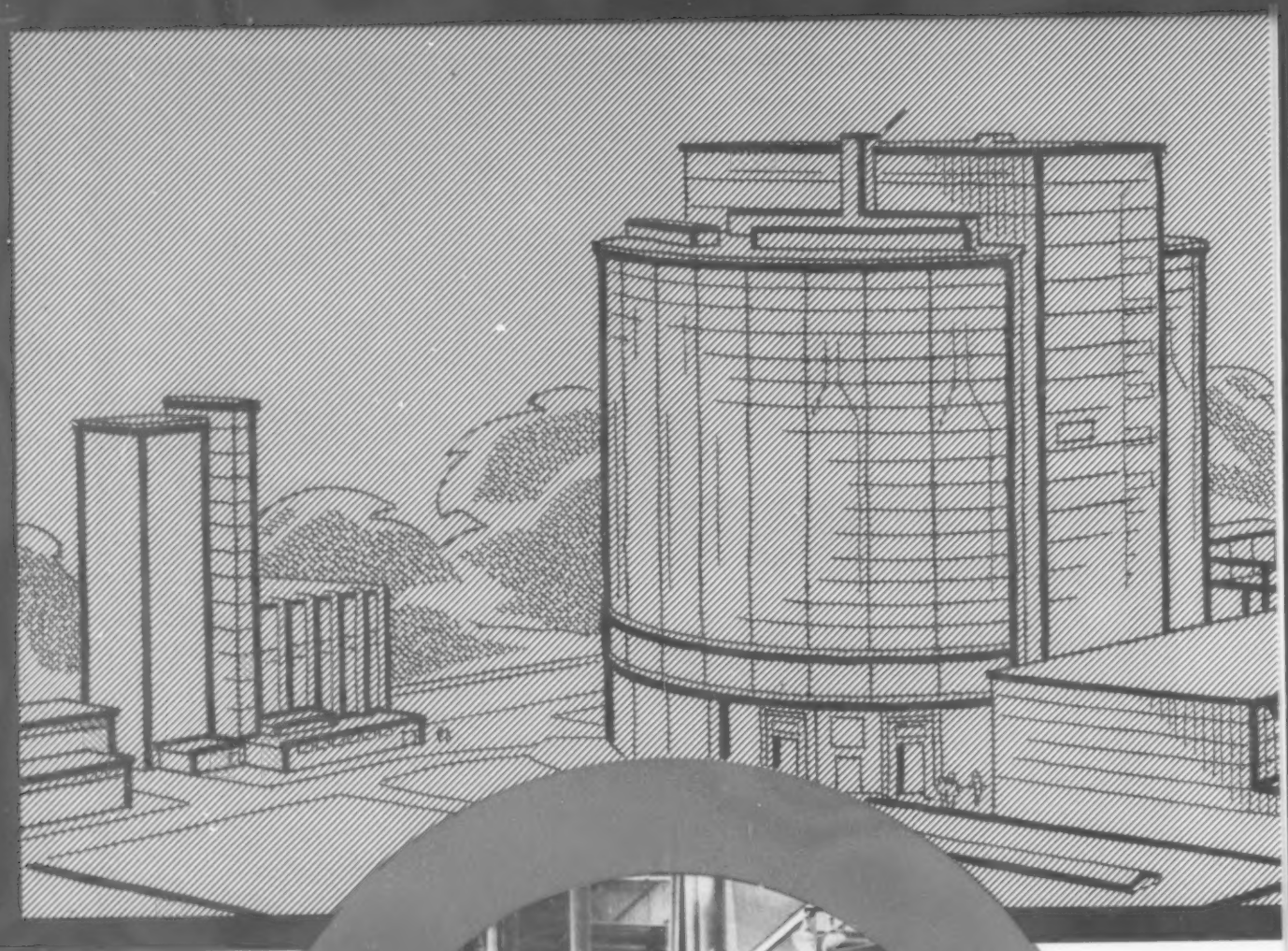
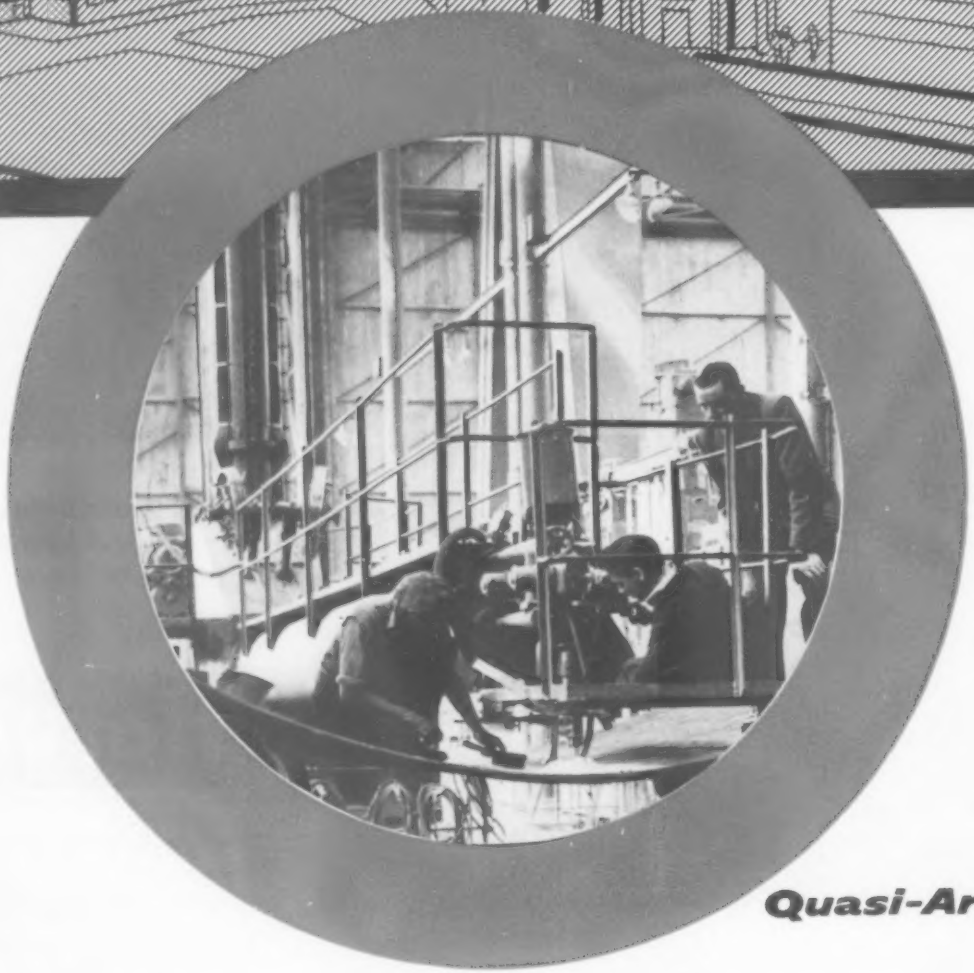
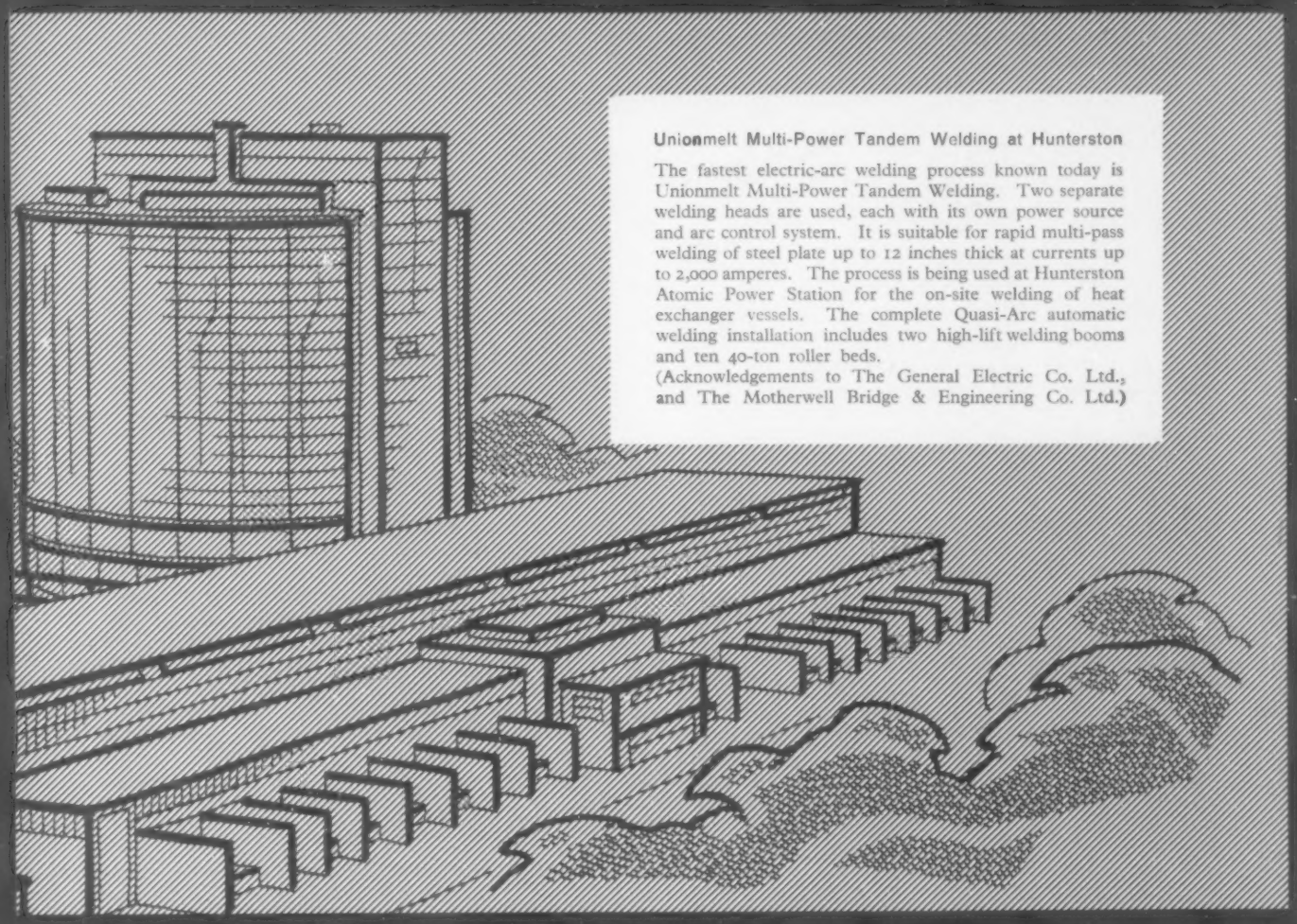




Quasi-Arc



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The fastest electric-arc welding process known today is Unionmelt Multi-Power Tandem Welding. Two separate welding heads are used, each with its own power source and arc control system. It is suitable for rapid multi-pass welding of steel plate up to 12 inches thick at currents up to 2,000 amperes. The process is being used at Hunterston Atomic Power Station for the on-site welding of heat exchanger vessels. The complete Quasi-Arc automatic welding installation includes two high-lift welding booms and ten 40-ton roller beds.
(Acknowledgements to The General Electric Co. Ltd., and The Motherwell Bridge & Engineering Co. Ltd.)

Quasi-Arc Unionmelt Automatic Welding

—for speed, economy and quality

THE UNIONMELT PROCESS

- automatic submerged-arc welding, depositing molten metal from a continuous bare wire electrode on to the parent metal through a blanket of flux powder.
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- wide range of welding heads—stationary and self-propelled—for a variety of duties.
- wide range of wires and powders available for various applications.
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- for details of the full range of Unionmelt equipment write for technical circular 102.

NEW British-made Unionmelt Powders

Quasi-Arc are pleased to announce that their well-established range of original Unionmelt powders is now being made in Great Britain under licence from the Union Carbide Corporation, U.S.A.

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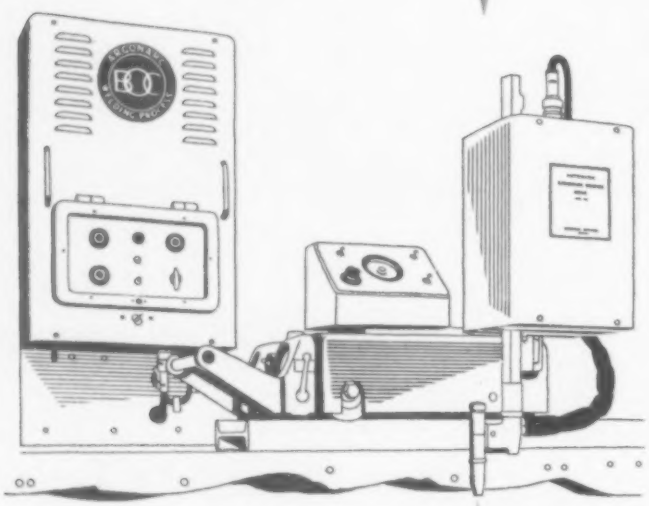

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New automatic
Argonarc welding head

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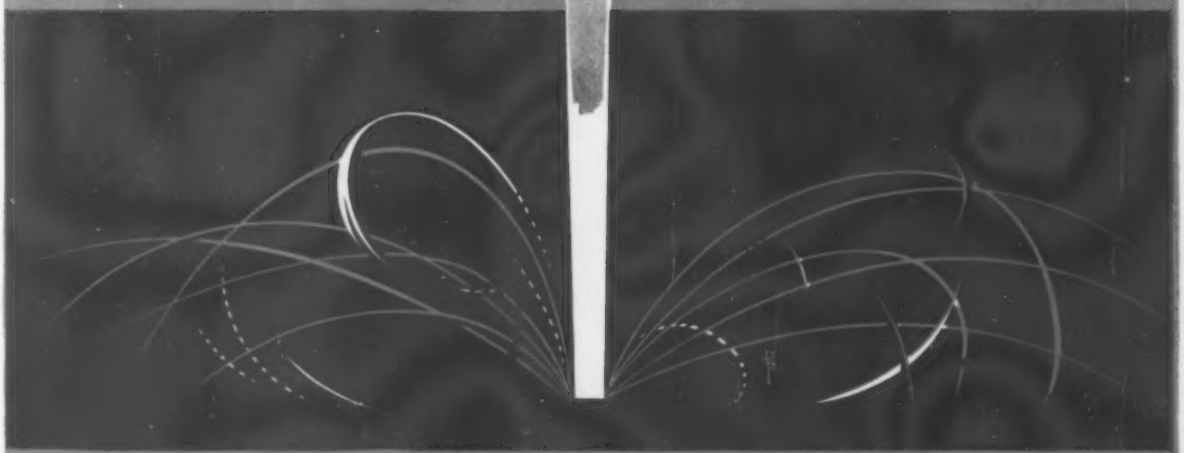

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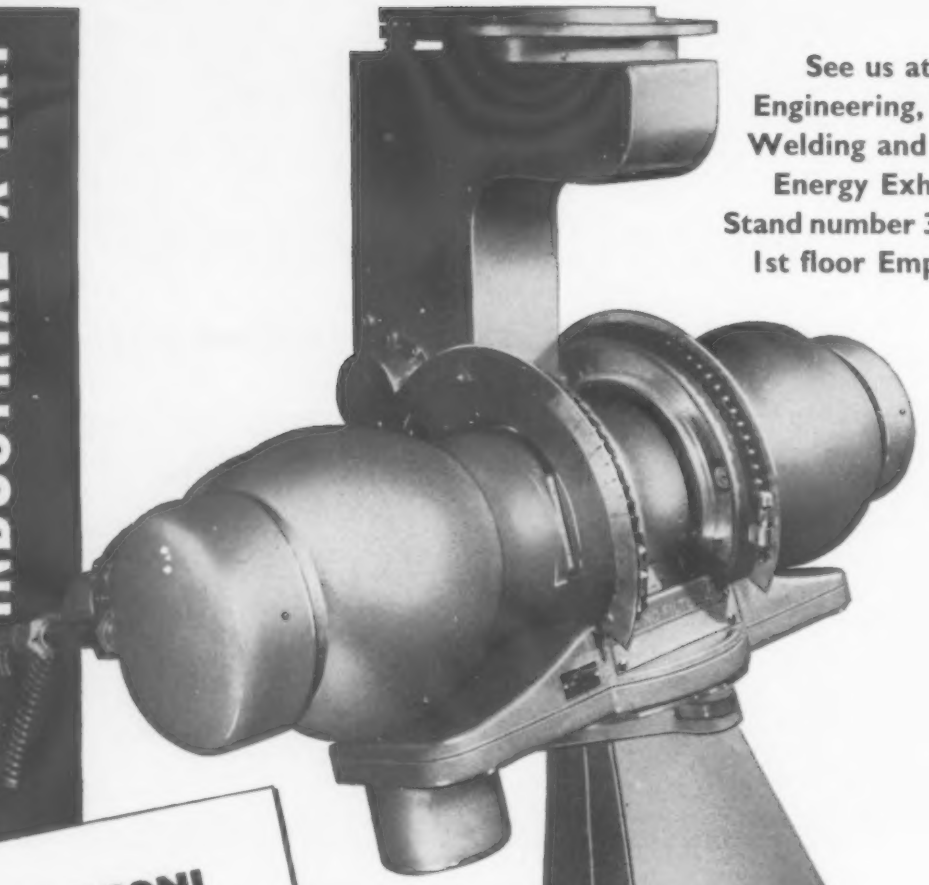

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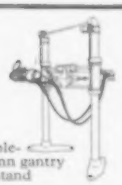

Double-column gantry tubestand

Dual-travel tube-stand

* *Let Marconi engineers help you in your choice of mountings. In addition to those shown, other tubehead mountings are available to suit specialized requirements.*

The Marconi 250-kV Constant Potential X-Ray equipment is one of the most efficient and versatile 'inspection tools' at the service of the engineering industry. The basic apparatus comprises four main items — a high tension transformer-rectifier unit, a control unit, an oil circulator/cooler and the oil-cooled tubehead illustrated above.

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IX 21

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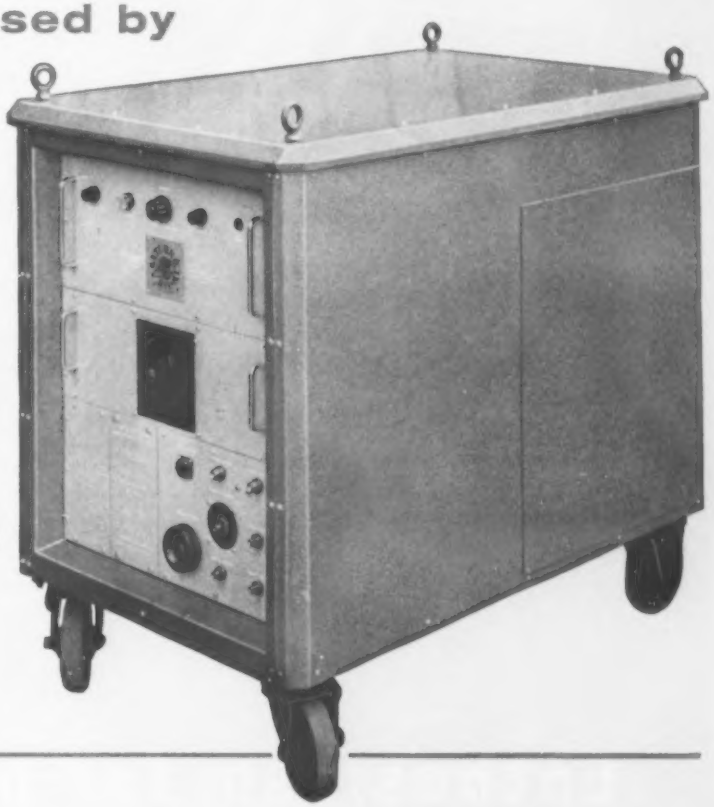

Speed up your production with the Saturn-Hivolt Surge Injector Argon Arc Welding Units Mk. II. and III. Completely self contained they have a built-in transformer and forced draught ventilation. Capable of continuous welding from 30 to 600 amps with a stable arc and complete operator safety.

Used for the welding of aluminium, its alloys and stainless steel. Saturn's efficient maintenance service from branches throughout the country inspires confidence. Many other leading industrialists are using Saturn-Hivolt machines with great success. Let us demonstrate to your production manager and welding experts what these machines can do to improve your production.

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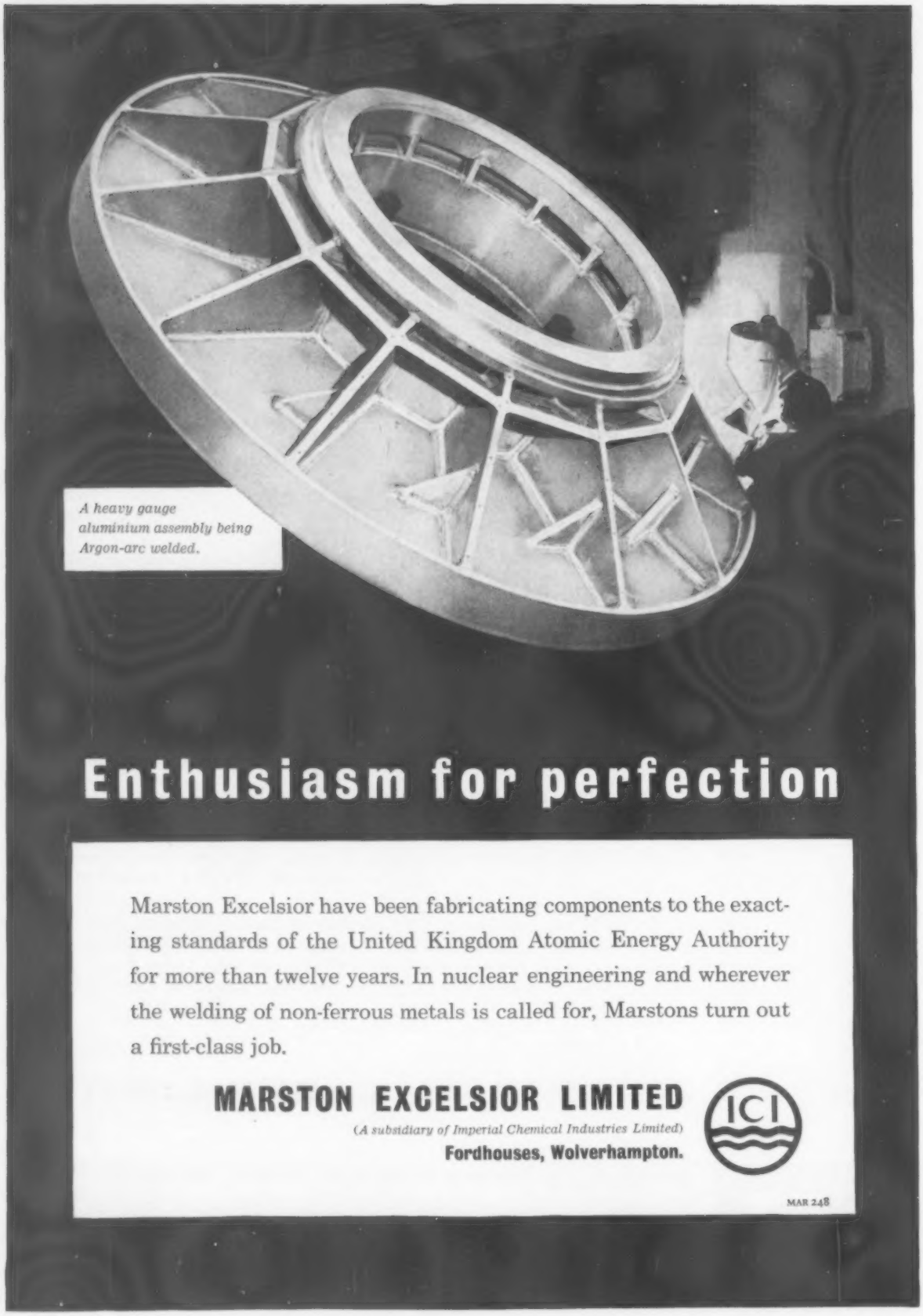

A heavy gauge aluminium assembly being Argon-arc welded.

Enthusiasm for perfection

Marston Excelsior have been fabricating components to the exacting standards of the United Kingdom Atomic Energy Authority for more than twelve years. In nuclear engineering and wherever the welding of non-ferrous metals is called for, Marstons turn out a first-class job.

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- Fully automatic tracing from a PENCIL LINE DRAWING.
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Which means that–

1. Templates are a thing of the past.
2. Anyone can make the drawings.
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4. The same drawing can be used for cuts in any thickness of plate.
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★*The machine is equipped of course with the Hancock patented roller drive—there is no physical contact between tracer and drawing*

★*The Hancoline is the ultimate in operational simplicity, and represents an ideal which has haunted all who have used machine oxygen cutting since the inception of the process.*

★*The Hancoline is covered by certain British Patent Applications.*

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A completely new dual carriage oxygen profiling machine, designed and built with traditional Hancock attention to detail.

★ Sleek enclosed machine tool appearance, protecting moving parts from dirt and dust.

★ New rigid box type construction.

★ New ease of maintenance. Unit construction of electrical equipment.

★ New electrically operated cutting oxygen valve with instant shut-off.

★ New tracer head for operation from templates of steel, wood, aluminium strip or direct from a drawing.

★ *In the New Hancomatic the tried and tested fundamentals of three decades of dual carriage machine construction are blended with modern design concepts in an aesthetic and functional unity previously unapproached.*

★ *There was never a machine like this before—not even in the Hancock range.*

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Progress Way, Croydon, Surrey. *Telephone: Croydon 1908.*

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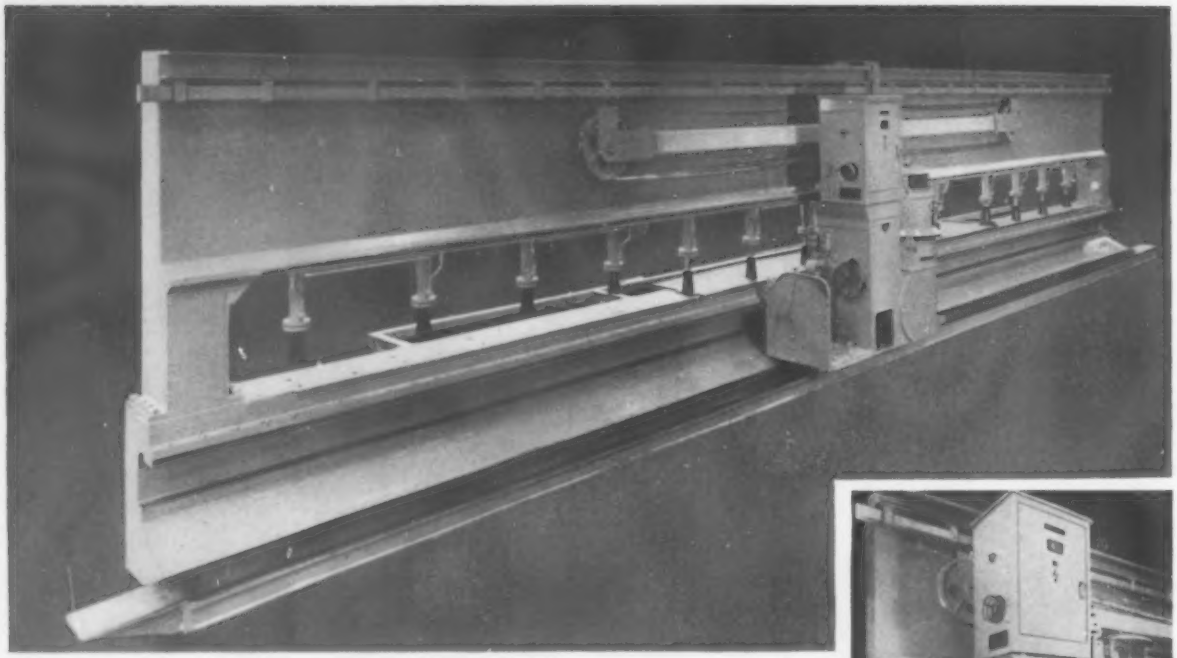

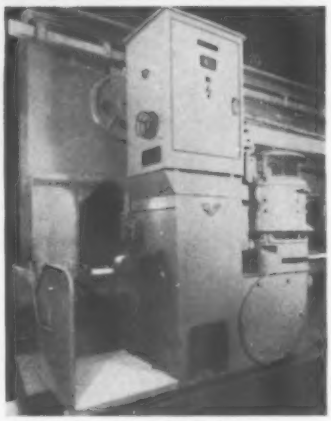

THE SADDLE AND CONTROLS

The HUGH SMITH "TRU-EDGE" PLATE EDGE PLANER

is the ideal machine for rapid and accurate preparation of plate edges for welded construction.

Very modern design developed over many years of experience, incorporating:

High efficiency worm gearing with single spiral rack pinion drive.

Wide main slide with replaceable inserts which can readily be replaned when necessary—fully protected by steel cover.

Unit construction tool standard, with motorised adjustment, built into the saddle.

2" square cutting tool—will plane plates or bundles of plates up to 2" thick.

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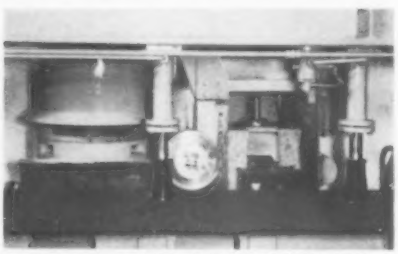
Swivel action available for planing bevels up to 35° either way.

High efficiency lighting on cutting tool and plate edge. Made with beam type clamping or hydraulic jack clamping (illustrated).

A rotary shearing head can be supplied which shears up to 1½" wide from plate edge with an accuracy of 0·01" in 40 ft.—much faster and more economical than flame cutting.

The machine is made in lengths of 25, 30, 35 and 40 ft.



ROTARY SHEAR WHEEL & PLANING TOOL BOX

BEAM TYPE CLAMPING MACHINE

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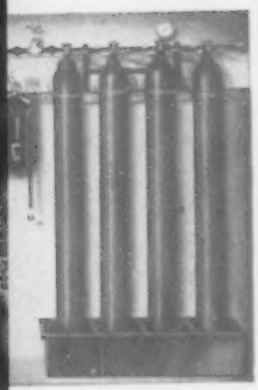
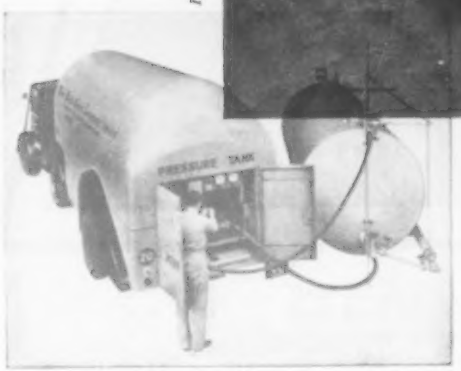
Hamiltonhill Road · Glasgow, N.2. · Scotland

We also make a full range of machines for manipulation of plates and sections BENDING ROLLS, STRAIGHTENING ROLLS, FLANGING PRESSES, GAP PRESSES, Etc.

Photograph illustrating the FUSARC CO_2 process by courtesy of Quasi-Arc Limited





The use of low pressure CO_2 gas as an inert shield in the welding of steels is increasing. CO_2 is not only cheap — it enables high quality welds to be made in the shortest time.

Where automatic welding machines have been specially modified to use this technique, the simplicity, ease of slag removal and high speed of welding have been found most impressive. On one differential housing, for example, welding time has been reduced from 105 to 23 seconds.

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The Carbon Dioxide Department of the D.C.L., with 30 years' experience of supplying CO_2 to industry, installs and maintains all necessary storage and gas supply equipment for CO_2 arc welding.

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. . . especially if you're worried about the efficiency of your welding.

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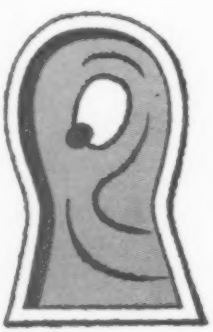
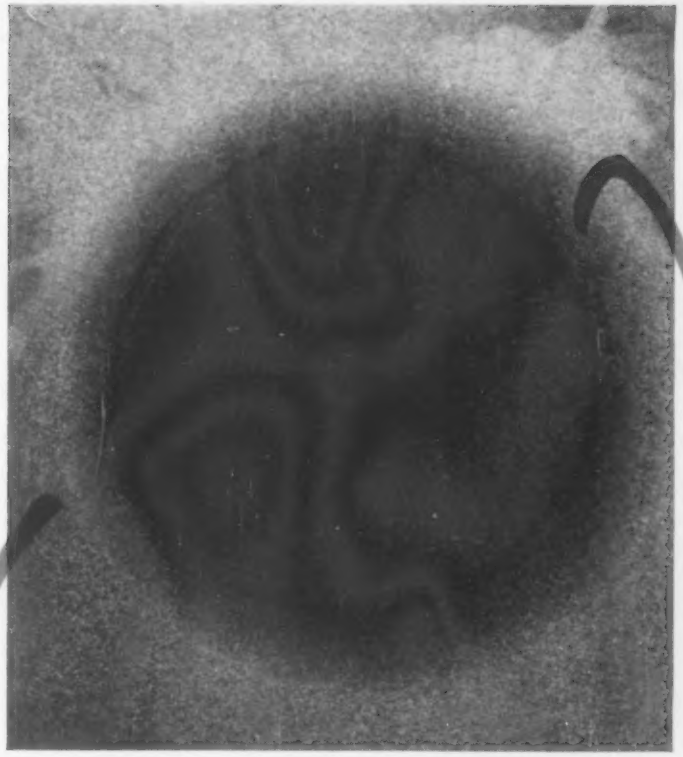
AGENTS THROUGHOUT THE WORLD





2mm + 2mm light alloy spot weld, magnified 7 times

It's new... it's faster... it's

ILFORD CX INDUSTRIAL X-RAY FILM

This new addition to the range of Ilford Industrial X-Ray films will give greatly improved radiographs of steel welds and light-metal castings. For examinations at up to 200 kVp it is twice as fast as Industrial C and with gamma-ray techniques it is as much as three times as fast. Because of its higher contrast and finer grain, it gives better definition than is possible with Industrial B. The inherent high contrast of Ilford CX makes this new film extremely useful for radiography with 1- and 2-million volt apparatus as well as with gamma rays. Ilford CX Industrial X-Ray film may be used with or without lead screens. The recommended developer is Ilford PQX-1.

Engineering, Marine, Welding & Nuclear Energy Exhibition

April 16th to 30th, Stand No. 5 BB, Empire Hall.

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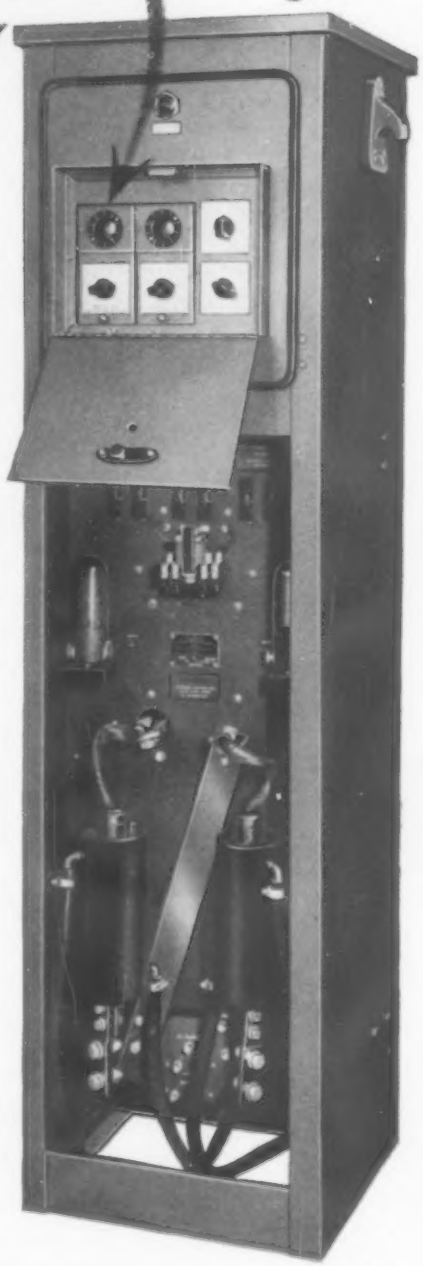
Electronic Welding-Control

with **dekatron** timing



* Maximum rating 2,400 kVA.

* For use with spot-welding or seam-welding machines.

* Provides accurate control of spot-welding time in one-cycle steps from one to ninety cycles; spot welds of half-cycle duration can be made by a simple adjustment.

* For seam-welding, both heat time and cool time are adjustable in one-cycle steps from one to nine cycles.

* Operates from single-phase, fifty-cycle supply (340-500 volts); weld-initiating circuit operates at 24 volts.

* Wide-range fine adjustment of welding current while welding is in progress.

* Visible indication on the dekatrons of weld duration.

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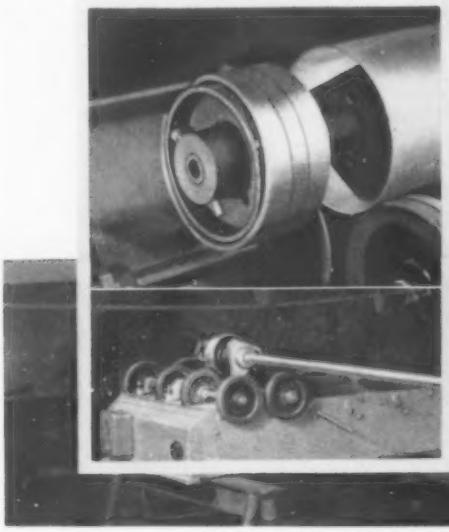
Of special interest are the Yates Internal Continuous Backing Bars and clamps, the new Self Propelled Carriage Rotator, the 40′ Universal Welding Column with 34′ Retractable Boom, and the *exclusive* Anti-Creep controls fitted to all Yates Rotators.
A comprehensive range of other new equipment will also be shown.



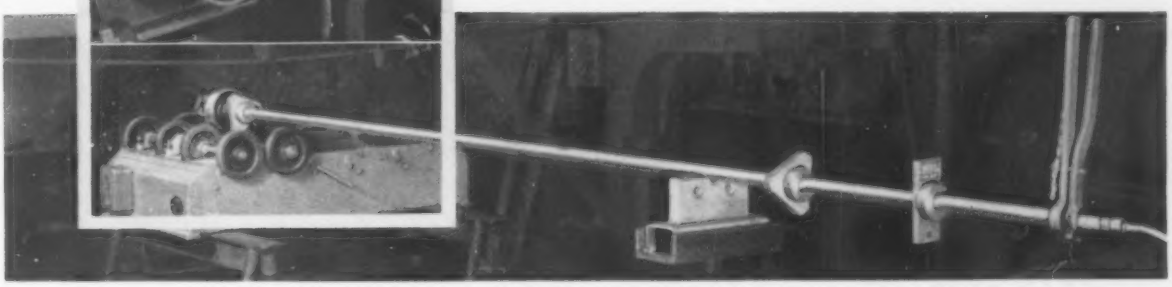
NEW! THE YATES BACKING BAR

This patented revolutionary device has three main functions:—

1 To provide a continuous Internal Backing so essential in Class I welding.

2 To securely clamp.

3 To accurately align the parts to be welded. A very special feature of the units is the provision for introducing inert gas behind the weld line.



NEW! YATES SELF PROPELLED CARRIAGE ROTATORS

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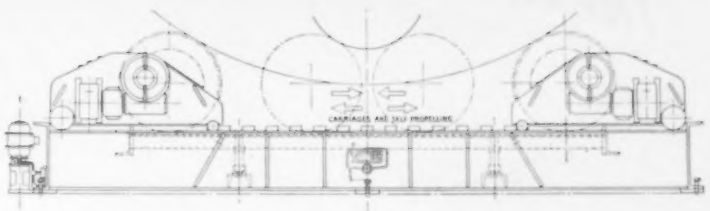

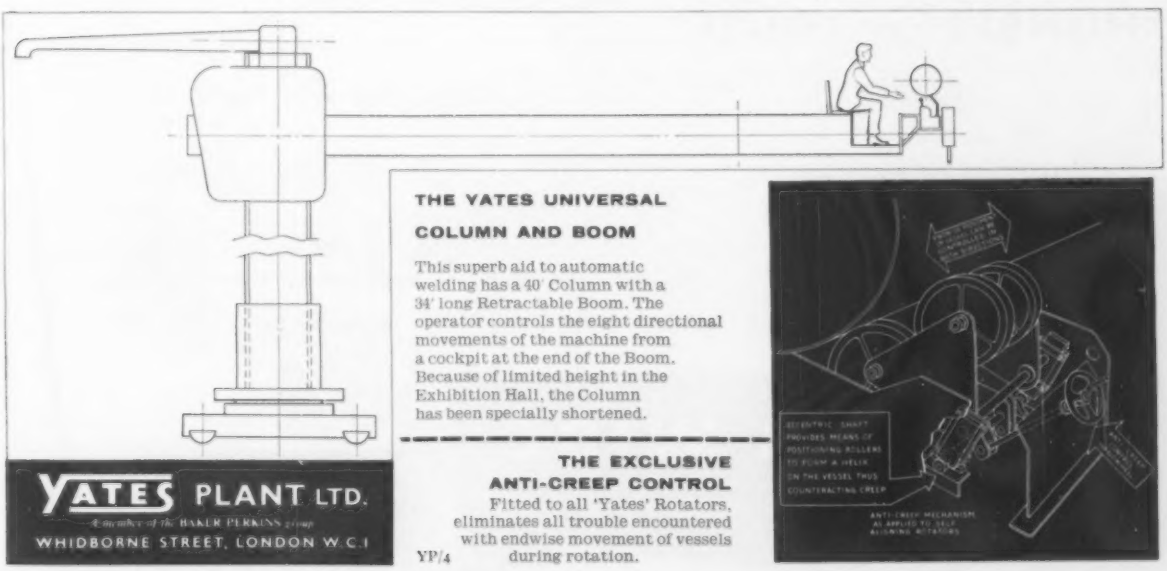

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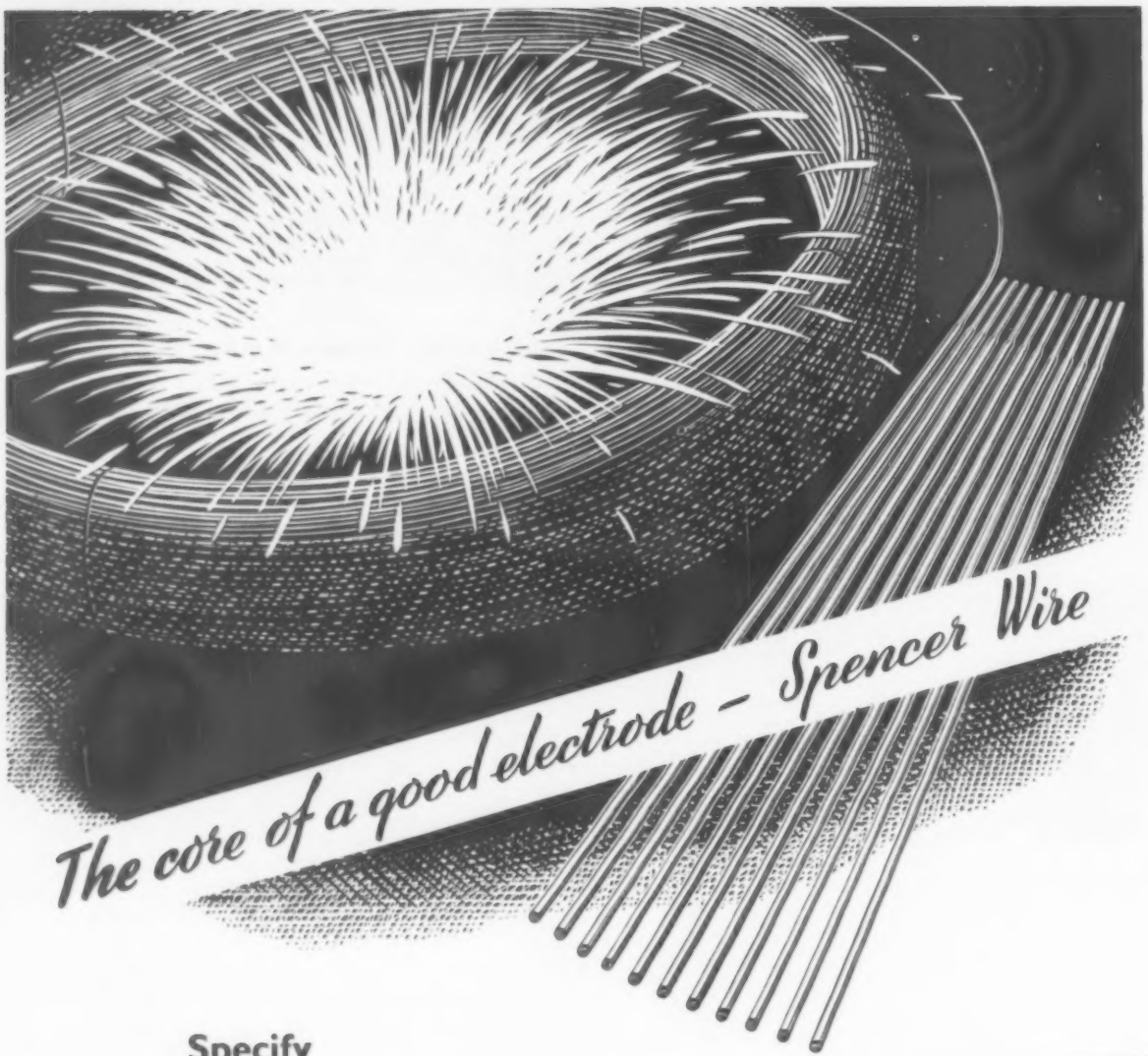

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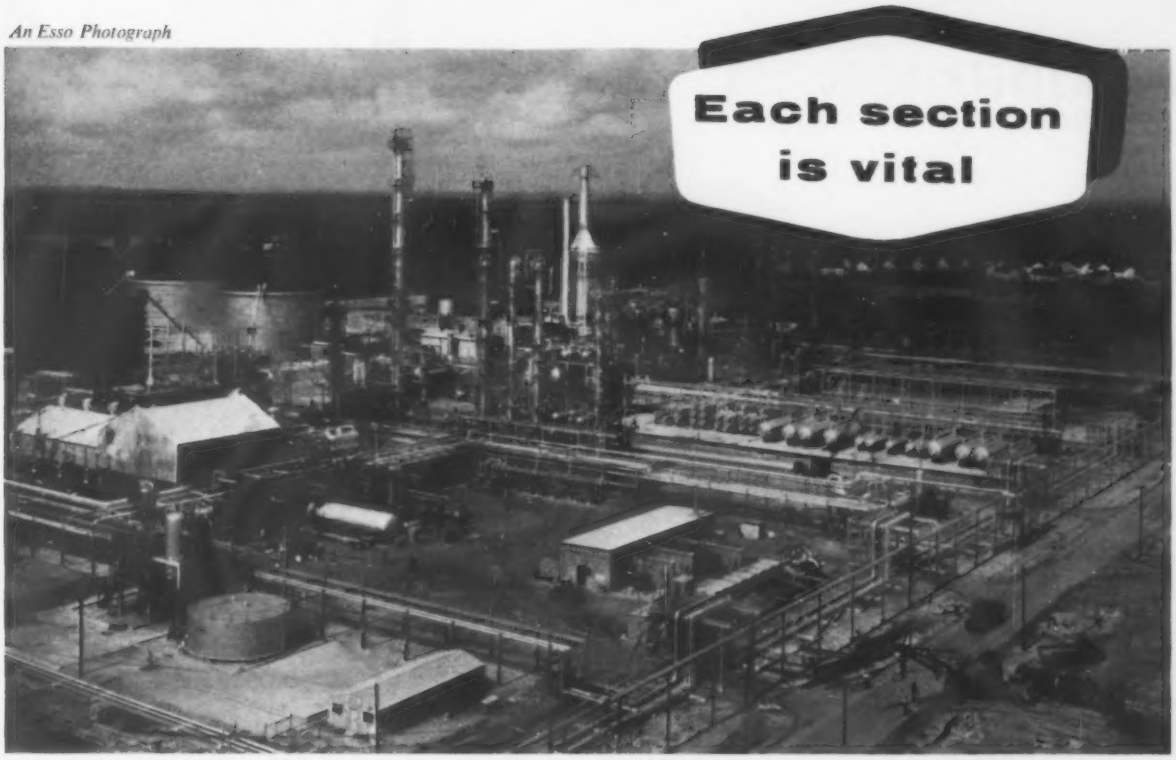

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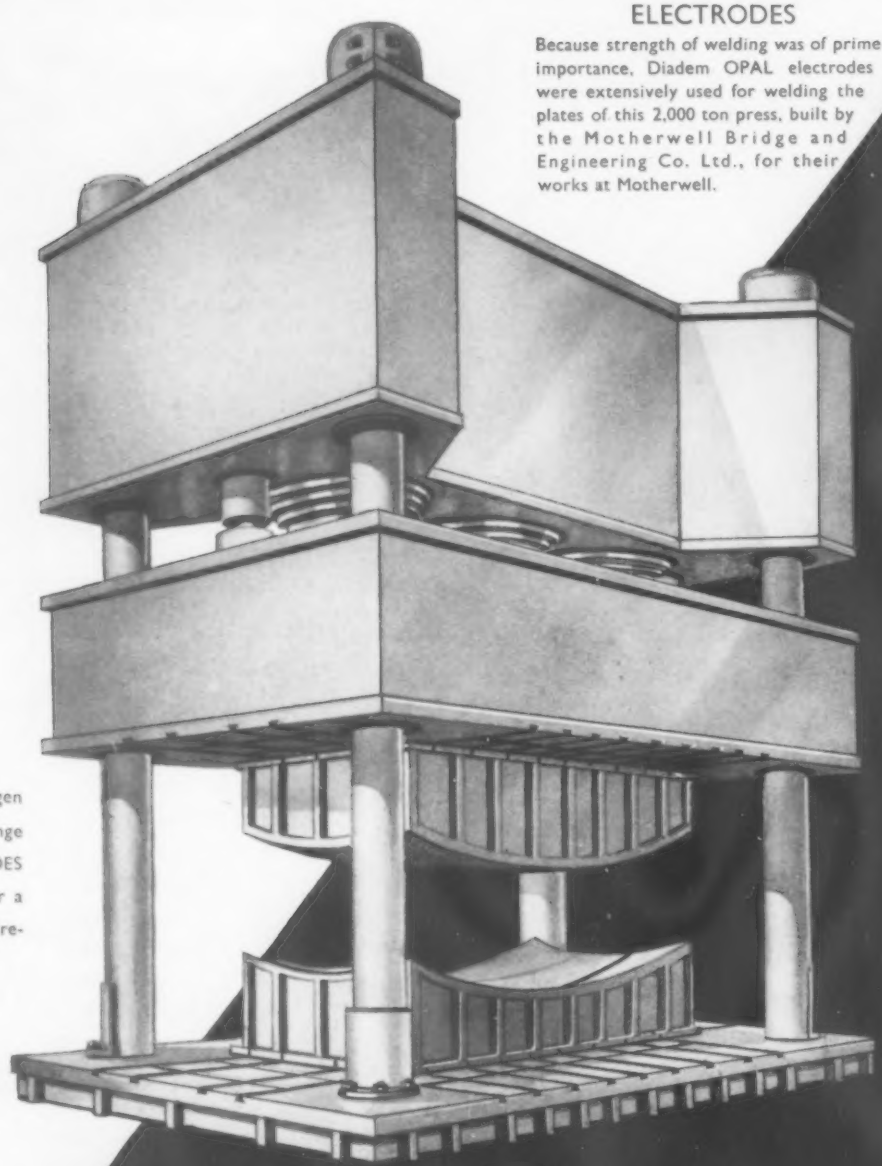

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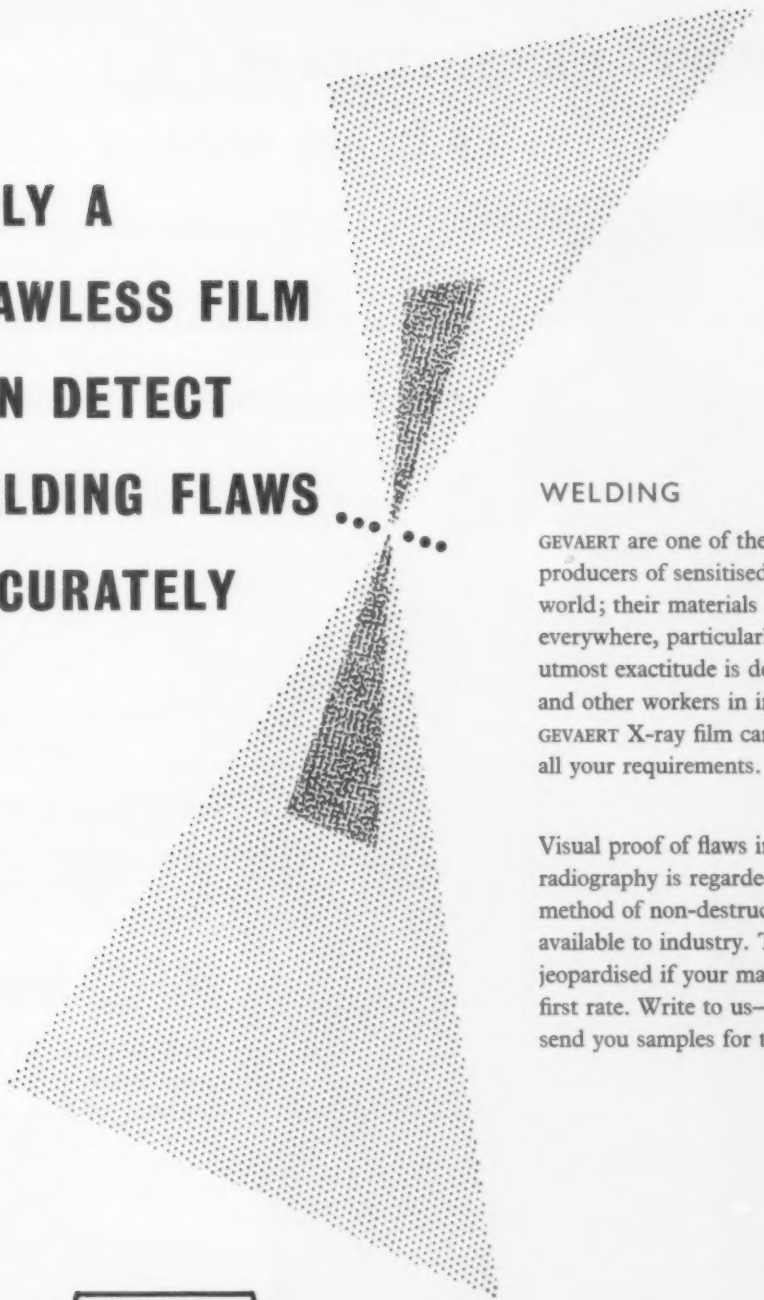

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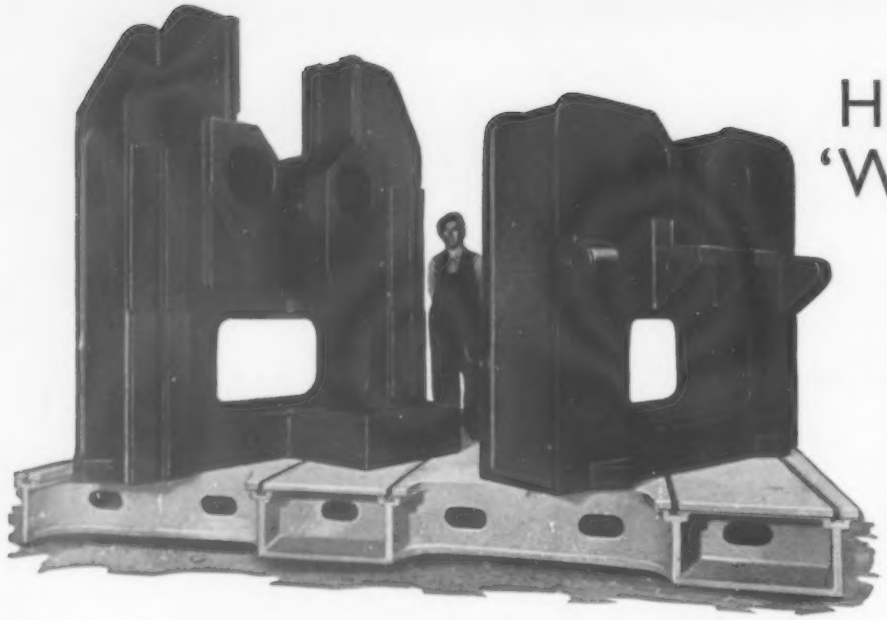

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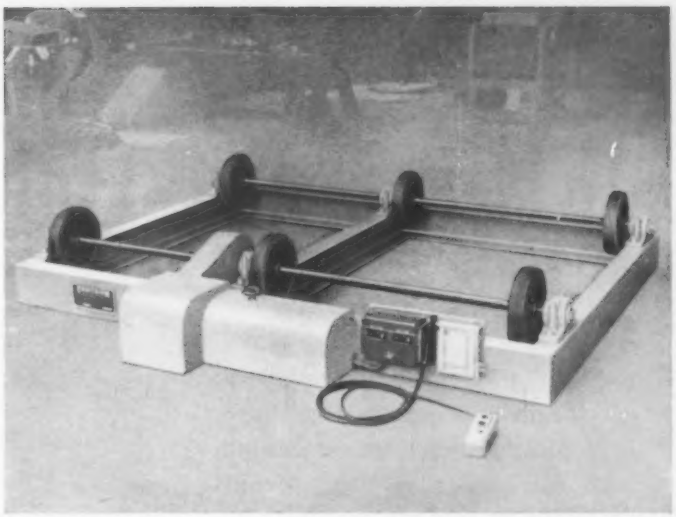

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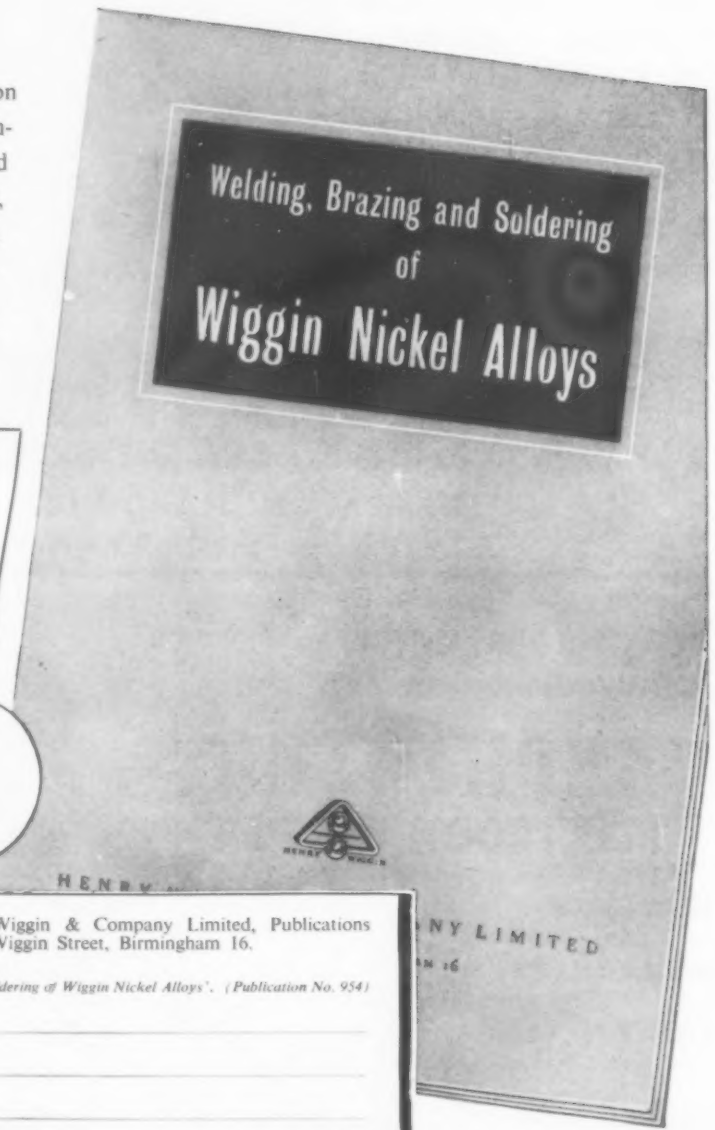

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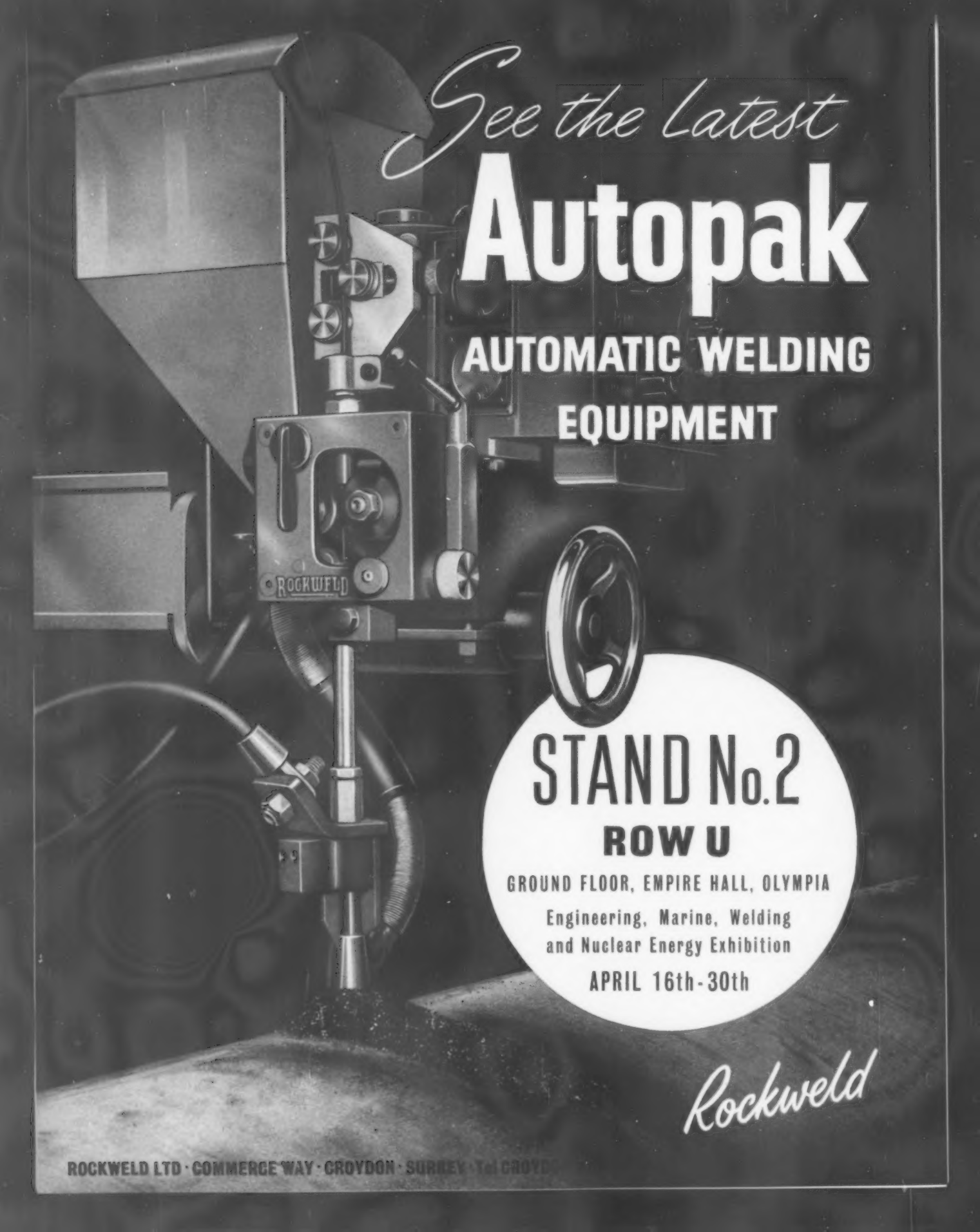
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TECHNOLOGY

Flange Deformations in the Welding of T-Sections

The author has studied the general nature of the bending of flange plates in **T** *and* **H** *sections, and has developed formulae for the determination of such deformation, based on the known welding conditions.*

A mass of experimental data has been compared with the theoretical values, and as a result it has been possible to construct simple graphs from which flange deformations can be estimated.

By N. O. Okerblom

DEFORMATION occurs in the plates when welding **T** and **H** sections, beams, and other types of 'abutting' joints between two plates using single or double fillet welds. The nature and amount of the deformation in the flange plates of **H**-beams is shown in Fig. 1*a*. Deformations occur similarly where ribs or other members are welded to a plate (Fig. 1*b*), with the sole difference that the general nature of the bending of the plate is changed as a result of the attachment to it of other members. If, in this second case, the same angle θ is assumed the examination may be confined to the deformation in flange plates arising from welding **T** sections. In bridge building these angular deformations have been called "mushroom type", and various empirical formulae and equations have been put forward for their determination.[1, 2, 3]

In addition, as a result of measurements of deformation made during the fabrication of **H** sections, various scientific research organizations (notably the Scientific Research Institute for Bridges under the Leningrad Engineering Institute of Rail Transport) have amassed a great amount of material on the angular deformations observed in industrial practice.

However, all this vast amount of material has not had enough theoretical development, and this is particularly necessary for the large number of factors which influence the nature and magnitude of the deformation θ. Further, the enumeration of these factors shows that empirical means cannot be used to allow for them in determining the deformations in flange plates. Actually the deformations θ depend on:

(i) The welding conditions (current, arc voltage, welding speed)

(ii) Characteristics of the welding materials (the weld seam factor for different electrodes and fluxes)

(iii) Sections and lengths of the welds (the weld leg, whether it is a convex or a concave weld, the total length and the length of separate sections of the weld)

(iv) Fillet weld deposition method (single or multipass welds, continuous or intermittent)

(v) Joint design and dimensions of the plates being welded (fillet weld on one side or both sides, the thicknesses of the table and the stalk)

(vi) Nature of penetration of the parent metal (the depth of penetration and shape of the penetration zone).

These many factors are interconnected, but the relationship may alter with changes in the general welding conditions.

This translation from the Transactions of the M.I. Kalinin Leningrad Polytechnic, No. 189, 1957, has been prepared for the British Welding Research Association by Major J. H. Dixon.

Right to the job with the RAYMAX 250 X-Ray Unit

BY HYDRAULIC LIFT TRUCK
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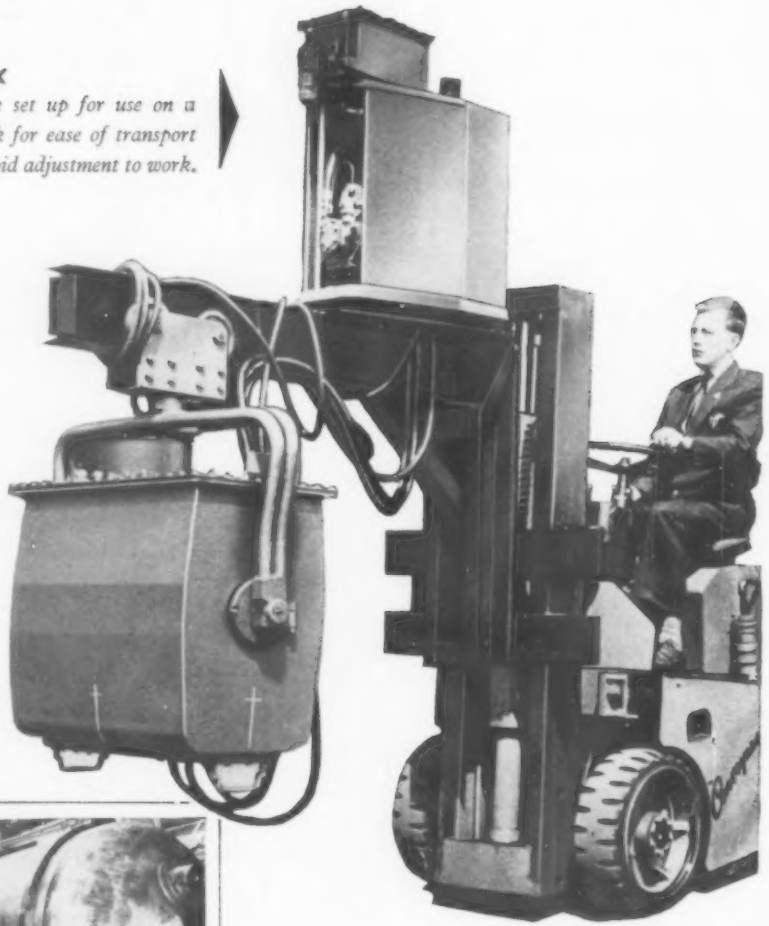

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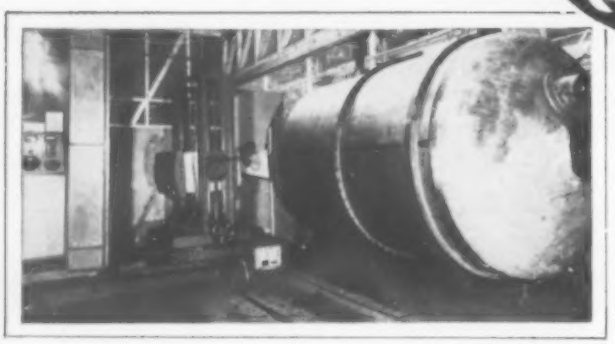

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Welding

TECHNOLOGY

Flange Deformations in the Welding of T-Sections

The author has studied the general nature of the bending of flange plates in **T** *and* **H** *sections, and has developed formulae for the determination of such deformation, based on the known welding conditions.*

A mass of experimental data has been compared with the theoretical values, and as a result it has been possible to construct simple graphs from which flange deformations can be estimated.

By N. O. Okerblom

DEFORMATION occurs in the plates when welding **T** and **H** sections, beams, and other types of 'abutting' joints between two plates using single or double fillet welds. The nature and amount of the deformation in the flange plates of **H**-beams is shown in Fig. 1*a*. Deformations occur similarly where ribs or other members are welded to a plate (Fig. 1*b*), with the sole difference that the general nature of the bending of the plate is changed as a result of the attachment to it of other members. If, in this second case, the same angle θ is assumed the examination may be confined to the deformation in flange plates arising from welding **T** sections. In bridge building these angular deformations have been called "mushroom type", and various empirical formulae and equations have been put forward for their determination.[1, 2, 3]

In addition, as a result of measurements of deformation made during the fabrication of **H** sections, various scientific research organizations (notably the Scientific Research Institute for Bridges under the Leningrad Engineering Institute of Rail Transport) have amassed a great amount of material on the angular deformations observed in industrial practice.

However, all this vast amount of material has not had enough theoretical development, and this is particularly necessary for the large number of factors which influence the nature and magnitude of the deformation θ. Further, the enumeration of these factors shows that empirical means cannot be used to allow for them in determining the deformations in flange plates. Actually the deformations θ depend on:

(i) The welding conditions (current, arc voltage, welding speed)

(ii) Characteristics of the welding materials (the weld seam factor for different electrodes and fluxes)

(iii) Sections and lengths of the welds (the weld leg, whether it is a convex or a concave weld, the total length and the length of separate sections of the weld)

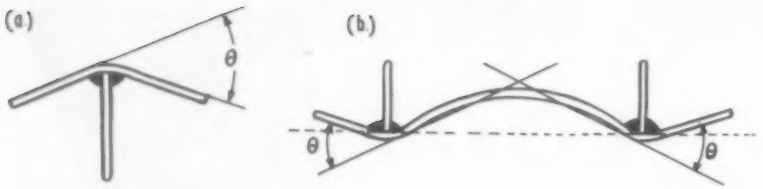
(iv) Fillet weld deposition method (single or multipass welds, continuous or intermittent)

(v) Joint design and dimensions of the plates being welded (fillet weld on one side or both sides, the thicknesses of the table and the stalk)

(vi) Nature of penetration of the parent metal (the depth of penetration and shape of the penetration zone).

These many factors are interconnected, but the relationship may alter with changes in the general welding conditions.

This translation from the Transactions of the M.I. Kalinin Leningrad Polytechnic, No. 189, 1957, has been prepared for the British Welding Research Association by Major J. H. Dixon.



1—*Angular deformations:* (a) **T**-*section flanges;* (b) *plates with ribs*

Thus, to obtain sufficiently reliable formulae and equations a detailed analysis must be made of all the processes involved in the occurrence and development of deformation in the flange plates during the welding of **T** sections.

Types of Deformation

As research carried out at the M.I. Kalinin Leningrad Polytechnic Institute shows,[4] the angular flange deformation occurring when a flange fillet weld is deposited on one side is the sum of deformations of two types:

(i) Deflection deformation of the flange plate as a rigid whole by a certain angle ω_1 owing to transverse contraction of the weld fibres parallel to the hypotenuse (Fig. 2*a*)

(ii) Bending deformation of the flange (Fig. 2*b*), due to its penetration to a certain depth, with deflection of the half-widths of the flange by an angle θ_1 to one another, the half-widths being located on both sides of the longitudinal flange weld (ignoring deformations caused by penetration of the rib).

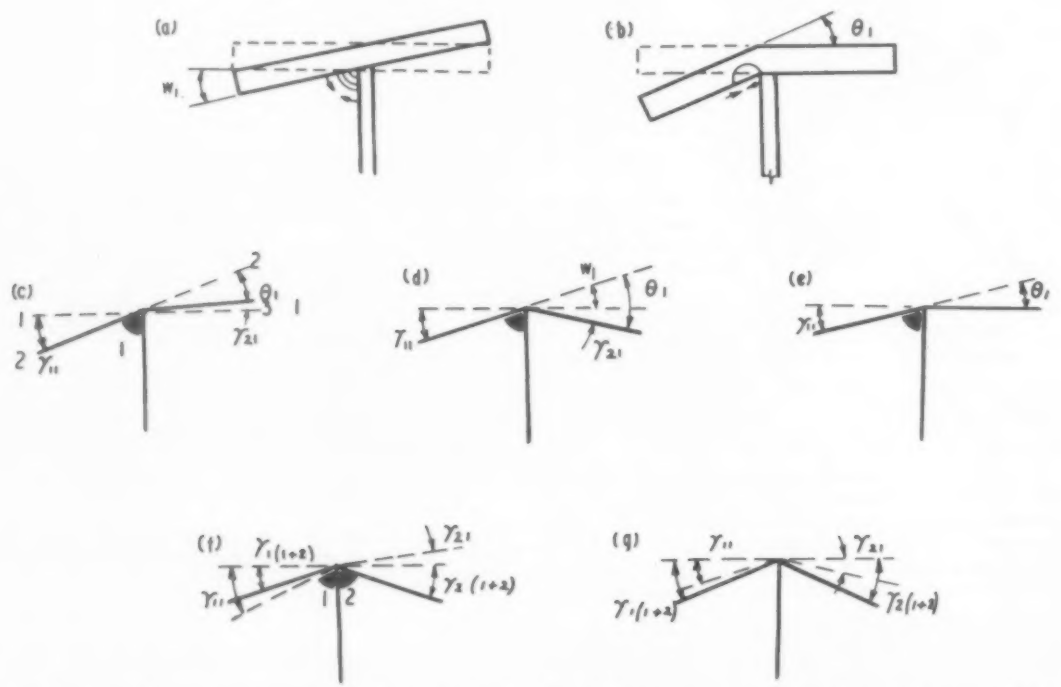
The total deformation of a flange plate from both causes will depend on the relationship between the angles ω_1 and θ_1. If the angle of deflection of the left half of the flange plate (weld 1) relative to its initial position is denoted by the angle γ_1, and that of the right half by γ_2, and assuming these angles to be negative where the corresponding half of the flange is bent down towards the rib, the angles γ_1 and γ_2 caused by depositing weld 1 may be expressed approximately (assuming the bend in the flange to be at the site of the weld) as:

$$\gamma_{11} = -\omega_1 \qquad \ldots\ \ldots\ \ldots\ \ldots\ (1)$$

$$\gamma_{21} = \omega_1 - \theta_1 \qquad \ldots\ \ldots\ \ldots\ \ldots\ (2)$$

Where $\theta_1 < \omega_1$, the angle γ_{21} will be positive (Fig. 2*c*); where $\theta_1 > \omega_1$, the angle γ_{21} will be negative (Fig. 2*d*); where $\theta_1 = \omega_1$, the angle γ_{21} will be zero, *i.e.*, the right hand half of the flange plate will remain in its initial position (Fig. 2*e*). The angle γ_{11} will always be negative.

When depositing weld 2, the deformation caused by the contraction of the hypotenuses will be limited,



2—**T**-*section table deformations caused by:* (a) *Contraction of fillet weld;* (b) *penetration into table;* (c) *single fillet weld where* $\theta < \omega$; (d) *the same, where* $\theta > \omega$; (e) *the same, where* $\theta = \omega$; (f) *double fillet welds, where* $\theta < \omega$; (g) *the same, where* $\theta > \omega$

owing to the fixing of the flange plate by the first weld. However, until the flange is caused to bend owing to its penetration by weld 2, the hypotenuse of the weld will contract naturally. Therefore, while both deformation processes are taking place the left half of the flange (weld 1) will not alter its position.

After the angle ω_2 or the angle θ_2 reaches a threshold value, further increase in one of these angles will result in alteration in the position of the left hand half-width of the flange plate as well. When this occurs the values of the angles γ_1 and γ_2 caused by the depositing of the two welds may be approximately expressed as:

$$\gamma_{1\,(1+2)} = -\omega_1 + \frac{\omega_2 - \theta_2}{2} \quad \ldots \quad (3)$$

$$\gamma_{2\,(1+2)} = \omega_1 - \theta_1 - \omega_2 + \frac{\omega_2 - \theta_2}{2} \quad \ldots \quad (4)$$

Where $\theta_2 < \omega_2$, the angle $\gamma_{1\,(1+2)}$ for the two welds proves to be less than the angle γ_{11} for one weld (Fig. 2*f*); where $\theta_2 > \omega_2$, the angle $\gamma_{1\,(1+2)} > \gamma_{11}$ (Fig. 2*g*). In the case where $\theta_2 = \omega_2$, the position of the left hand half-width of the flange plate will remain unchanged, *i.e.*, $\gamma_{1\,(1+2)} = \gamma_{11}$.

It follows from these equations that for fillet welds on both sides the full bending of a flange plate will be:

$$\theta_{(1+2)} = -\gamma_{1\,(1+2)} - \gamma_{2\,(1+2)} = \theta_1 + \theta_2 \quad \ldots \quad (5)$$

Thus, to determine the 'mushroom shape' it is sufficient to know the angle of bend of the flange due to its penetration during the deposition of both flange welds. To determine the deflection of the bent plate it is necessary also to know the angles of deflection caused by the contraction of the hypotenuses of each of the fillet welds.

Deformation from Single Fillet Weld

The angle of deflection of a flange plate when a flange joint is deposited on one side may be determined from an examination of the contraction of the hypotenuse of the fillet weld during cooling. For a fillet weld leg equal to k, the length of the hypotenuse is $1{\cdot}4\,k$, and in consequence its contraction on cooling by $T°$ is

$$\Delta = \alpha T\, 1{\cdot}4\, k.$$

Contraction of the hypotenuse of this nature causes one of the plates connected by the fillet weld to be deflected relative to the other plate by the angle

$$\omega_1 = \frac{\Delta}{0{\cdot}7k} = 2\alpha T. \quad \ldots \quad (6)$$

Research proved that the amount αT may be taken as approximately 0·012, corresponding to a temperature $T \cong 750$–$800°$ (taking α as dependent on T).

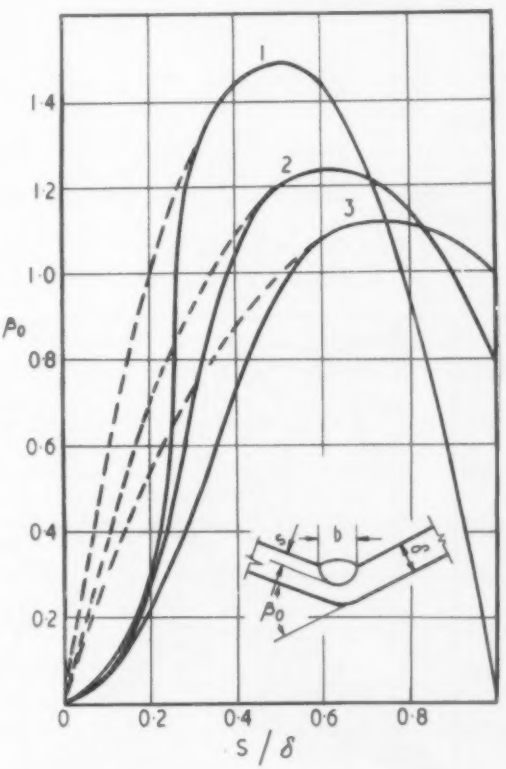
Thus it follows from equation (6) that the angle ω_1 does not depend on the leg of the weld, nor does it in consequence depend on the welding conditions if the fillet weld is deposited in the form of an isosceles right-angled triangle.

The angle of bend θ of a flange plate on the deposition of a single fillet weld which is equal to the angular deformation β of a plate due to the deposition of a bead on its surface, and which is equal to 2β for a flange joint deposited on both sides under the same welding conditions, depends on the depth of penetration and on the shape of the penetration zone, and consequently on the welding conditions and the thickness of the flange plate.

Theoretical Determination of Angular Deformation

The angular deformations of a plate when a bead is deposited on its surface were investigated by Baikova.[7] The research resulted in the establishment of a theoretical method for determining the angular deformation β, enabling not only the welding conditions, width of bead, and thickness of plate to be taken into account but also the lengths of plate and bead.

On the basis of this research the author and Baikova jointly proposed a simplified method for determining the angular and transverse deformation when a bead is deposited simultaneously along its entire length, but taking the depth and shape of the penetration zone into account.[4] This approximate method of determining angular deformations is based on the assumption that the magnitude of these angular deformations is principally determined by the contraction of the metal in the penetration zone on cooling. Comparison of the angular deformations produced experimentally, on the basis of accurate calculation, and by the proposed simplified method proved that no material error is inherent in the simplified method. It is thus possible to determine the angular deformations β_0 for short welds. Figure 3 is a graph for the change in the ratio



3—*Relationship between ratio* $m = \dfrac{\beta_0}{\alpha T \frac{b}{\delta}}$ *and the relative depth of penetration of plate*

$m = \dfrac{\beta_0}{\alpha T \dfrac{b}{\delta}}$ with relation to the relative depth of penetration (s/δ) for three penetration zone shapes: (1) square, (2) confined within a parabola, and (3) triangular.

Using the well-known relationship between F_{pen}, the area of the penetration zone, and the energy expended per unit run,

$$F_{pen} = \frac{q_{t.pen}}{A}$$

where $q_{t.pen}$ = the energy expended per unit run on melting the parent metal, assumed on average to be $0{\cdot}3 \times q_t$, the total energy expended per foot run

A = the number of calories of heat required to melt 1 cu.cm of parent metal, taken from now on as 3900 cal/cu.cm.

and if it is assumed that the area F_{pen} may be expressed by means of the width b and depth s of the penetration zone as follows,

$$F_{pen} = \rho b s$$

where ρ is a coefficient depending on the shape of the penetration zone,

the relationship s/δ may be expressed by:

$$s/\delta = \frac{F_{pen}}{\rho b \delta} = \frac{q_{t.pen}}{3900\, \rho b \delta^2}.$$

If b, the width of the bead, is expressed as a function of δ, the plate thickness:

$$b = \xi \delta$$

then

$$s/\delta = \frac{q_{t.pen}}{3900\, \rho \xi \delta^2},$$

whence

$$\frac{q_{t.pen}}{\delta^2} = 3900\, \rho \xi \frac{s}{\delta} \quad .. \quad .. \quad .. \quad .. \quad (7)$$

The angular deformation β_0 may accordingly be expressed by

$$\beta_0 = m a_1 T \frac{b}{\delta} = m \xi a T. \quad .. \quad .. \quad .. \quad (8)$$

Using values of m from the graph in Fig. 3, it is possible to plot the relationship of β_0 to $q_{t.pen}$ for different values of ξ. This relationship is given in Fig. 4 for the most probable form of the penetration zone as a parabola ($\rho = 0{\cdot}67$).

The value of β_0 is valid only for lengths of bead for which the heating conditions at the end of welding correspond to those where the full length of a bead is deposited simultaneously. It may be assumed as an approximation that these conditions will correspond if, at the moment when welding ends, the parent metal beneath the bead is in the plastic state, *i.e.*, is at a temperature exceeding 500°C.

The length x of plate and bead at which the temperature along the axis of the bead is equal to T_x may be determined from the well-known equation[8]

$$T_x = \frac{1}{2\sqrt{\pi \lambda c \gamma}} \cdot \frac{q}{\delta \sqrt{vx}} = D \frac{q}{v\delta} \sqrt{\frac{v}{x}}$$

For mild steel $D = 0{\cdot}85$. Where $T_x = 500°$ the value of x is determined by

$$x = \left(\frac{D}{T_x}\right)^2 \cdot \left(\frac{q_t}{\delta}\right)^2 v = 2{\cdot}89 \times 10^{-6} \left(\frac{q_t}{\delta}\right)^2 v. \quad .. \quad .. \quad .. \quad (9)$$

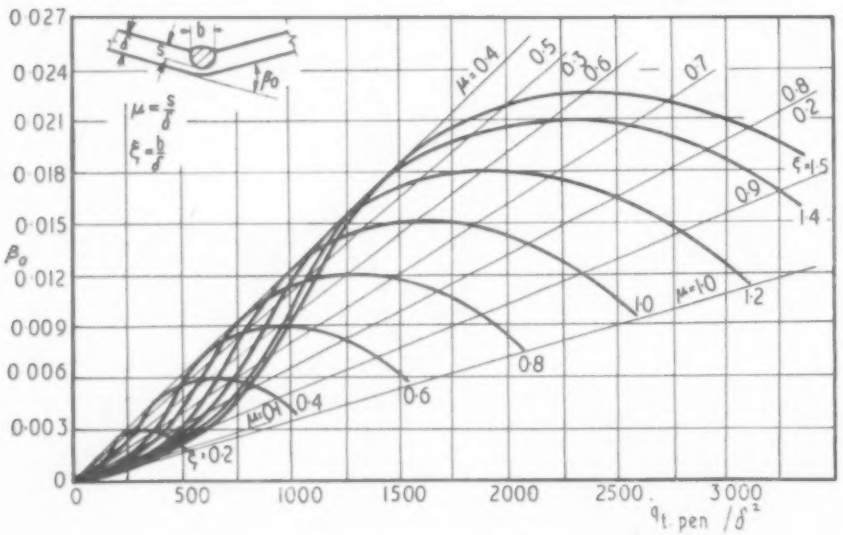
Where the effective length L exceeds x, the angular deformations $\beta_e > \beta_0$. It was proved in Baikova's research that as L, the length of bead and plate, increases, the angular deformations increase, approaching their ultimate value β_{max}, at a certain critical length L_{crit}.

As an approximation, based on a number of calculated and experimental data, it can be assumed that

$$\left.\begin{aligned} L_{crit} &= 9x \\ \beta_{max} &= 3\beta_0 \end{aligned}\right\} \quad .. \quad .. \quad .. \quad .. \quad (10)$$

For intermediate values of length between $9x$ and x, the values of β_e may be taken from the linear relationship given graphically in Fig. 5.

Thus, using equations (6), (9), and (10) and the curves in Fig. 4, the values of the angles ω and θ can be determined, and also in consequence the values of the angles γ_1 and γ_2.



4—*Relationship between angular deformation β_0 and ratio $\frac{q_{t.pen}}{\delta^2}$*

Experimental Results

To confirm that the proposed equations are sufficiently accurate for practical purposes, the results of Baikova's experiments on angular deformation in the welding of **T**-sections can be cited. Deformations were measured during the fabrication of **T**-sections consisting of a 115×6 mm stalk and a table 120 mm wide, its thickness varying between 6 and 15 mm. The lengths of all the sections $L=500$ mm. An *ADS*-1000 automatic welding machine was used. Before welding, the **T**-sections were tack-welded. Table I gives the welding conditions for each specimen and the values for energy per unit run reaching the flange plate, determined from the equation

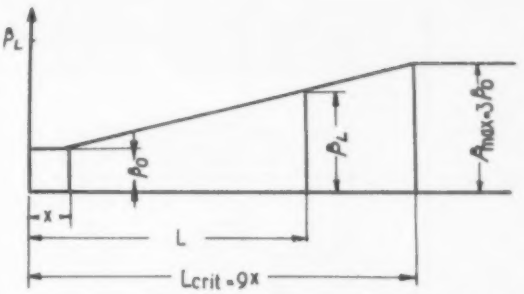
$$q_t = \frac{0{\cdot}24 \times 0{\cdot}7 \times IU}{v} \cdot \frac{2\delta_t}{2\delta_t + \delta_s} \quad \ldots \quad \ldots \quad \ldots \quad (11)$$

where δ_t and δ_s are the thicknesses of the table and stalk of the **T**-section respectively.

The value of $q_{t.pen}$ was determined from the equation

$$q_{t.pen} = 0{\cdot}43\, q_t \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

After each of the two welds had been deposited, the angle of bend θ of the flange and the angles of deflection γ_1 and γ_2 of the two half widths of the flange relative to the vertical stalk were measured. Table I gives values obtained for these angles in radians.



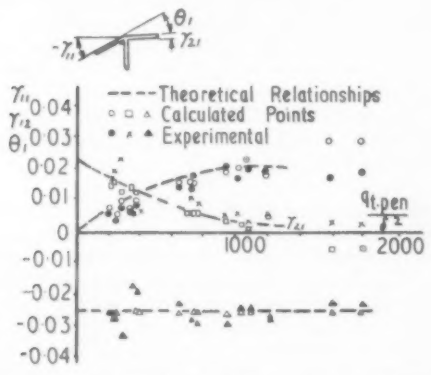
5—Approximate relationship between angular deformations and length of bead (plate)

Table II gives the values calculated for these angles. To determine the angles θ, γ_1, and γ_2 the values of the length x at which welding was considered to be performed simultaneously along the whole length were calculated by equation (9). The angular deformations $\theta_1=\beta_e$ were determined by equations (10) from the relationship of the actual length L to the length x.

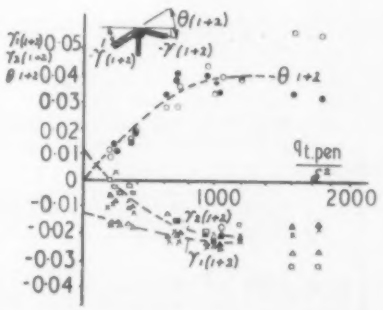
Table I

Experimental conditions for tests on T sections

Test No.	δ_t, *mm*	*I, amp*	*U, volts*	*v, cm/sec*	*k, mm*	q_t, *cal/cm*	$q_{t.pen}$ *cal/cm*	$\frac{q_{t.pen}}{\delta^2_t}$	γ_{11}	γ_{21}	θ_1	$\gamma_{1(1+2)}$	$\gamma_{2(1+2)}$	$\theta_{(1+2)}$
16	6·25	450	29	1·67	4	862	370	948	−0·0268	+0·0049	−0·0218	−0·0183	−0·0227	−0·0410
16a	6·00	450	29	1·67	4	862	370	1027	−0·0230	+0·0058	−0·0172	−0·0207	−0·0177	−0·0384
16b	5·87	550	26	1·67	4	950	407	1185	−0·0256	+0·0061	−0·0195	−0·0198	−0·0201	−0·0399
17	6·00	450	29	0·96	8	1510	648	1800	−0·0215	+0·0017	−0·0198	−0·0157	−0·0166	−0·0323
17a	6·37	450	29	0·96	8	1510	648	1600	−0·0215	+0·0018	−0·0177	−0·0160	−0·0180	−0·0340
18	8·75	450	29	1·39	4	1156	495	650	−0·0215	+0·0073	−0·0142	−0·0116	−0·0227	−0·0343
18a	8·25	450	29	1·39	4	1156	495	728	−0·0268	+0·0122	−0·0146	−0·0190	−0·0192	−0·0382
18b	7·80	550	26	1·67	4	1050	450	740	−0·0279	+0·0102	−0·0177	−0·0183	−0·0224	−0·0407
19	7·95	420	29	0·96	8	1550	667	1055	−0·0233	+0·0032	−0·0201	−0·0187	−0·0157	−0·0344
19a	8·27	450	29	0·96	8	1675	717	1045	−0·0230	+0·0029	−0·0201	−0·0218	−0·0178	−0·0396
20	14·67	450	29	1·39	4	1320	568	264	−0·0326	+0·0239	−0·0087	−0·0157	−0·0029	−0·0128
20a	15·50	450	29	1·39	4	1320	568	236	−0·0253	+0·0201	−0·0052	−0·0070	−0·0081	−0·0151
20b	15·20	550	26	1·39	4	1200	515	222	−0·0250	+0·0180	−0·0064	−0·0043	−0·0096	−0·0133
21	14·57	450	29	0·96	8	1910	820	389	−0·0177	+0·0078	−0·0099	−0·0087	−0·0108	−0·0195
21a	15·00	450	29	0·96	8	1910	820	365	−0·0166	+0·0081	−0·0085	−0·0096	−0·0070	−0·0166



6—Experimental relationships between angular deformations of table plates and welding conditions for single fillet weld between stalk and table



7—Experimental relationships between angular deformations of table plates and welding conditions for double fillet welds between stalk and table

Table II

Calculated angular deformations

Test No.	q_1	q_1/δ_1	$\left(\frac{q_1}{\delta_1}\right)^2 \times 10^{-6}$	$2{\cdot}89v$	x	$\frac{L}{x}$	$0{\cdot}25\times\left(\frac{L}{x}+3\right)$	$\xi=\frac{k}{\delta_1}$	$\frac{q_{t.pen}}{\delta_1^2}$	β_0	$\theta-\beta_0$	γ_{21}	γ_{21}	$\gamma_{1(1+2)}$	$\gamma_{2(1+2)}$	θ_{1+2}
16	862	1380	1·90	4·82	9·15	5·48	2·11	0·64	948	0·0095	0·020	−0·024	+0·0040	−0·0220	−0·0180	−0·0400
16a	862	1435	2·06	4·82	9·90	5·05	2·05	0·67	1027	0·0100	0·0205	−0·024	+0·0035	−0·0223	−0·0188	−0·0410
16b	950	1620	2·62	4·82	12·60	3·96	1·74	0·68	1185	0·0105	0·0183	−0·024	+0·0057	−0·0211	−0·0155	−0·0366
17	1510	2510	6·30	2·77	17·45	2·86	1·46	1·33	1800	0·0195	0·0285	−0·024	+0·0045	−0·0262	−0·0307	−0·0570
17a	1510	2380	5·66	2·77	15·60	3·20	1·55	1·26	1600	0·0185	0·0287	−0·024	+0·0047	−0·0263	−0·0310	−0·0574
18	1156	1320	1·74	4·01	6·98	7·17	2·54	0·46	650	0·0065	0·0164	−0·024	+0·0076	−0·0202	−0·0126	−0·0328
18a	1156	1400	1·96	4·01	7·85	6·38	2·35	0·49	728	0·0070	0·0164	−0·024	+0·0076	−0·0202	−0·0126	−0·0328
18b	1050	1345	1·81	4·82	8·71	5·73	2·19	0·51	740	0·0075	0·0164	−0·024	+0·0076	−0·0202	−0·0126	−0·0328
19	1550	1950	3·80	2·77	10·52	4·75	1·94	1·90	1055	0·0125	0·0230	−0·024	+0·0010	−0·0295	−0·0225	−0·0460
19a	1675	2030	4·12	2·77	11·40	4·39	1·84	0·97	1045	0·0125	0·0230	−0·024	+0·0010	−0·0235	−0·0225	−0·0460
20	1320	900	0·81	4·01	3·25	15·40	3·00	0·27	264	0·0035	0·0105	−0·024	+0·0135	−0·0173	−0·0038	−0·0210
20a	1320	855	0·73	4·01	2·93	17·10	3·00	0·26	236	0·0023	0·0069	−0·024	+0·0171	−0·0155	−0·0015	−0·0138
20b	1200	790	0·62	4·82	2·99	16·80	3·00	0·26	222	0·0025	0·0075	−0·024	+0·0165	−0·0158	−0·0007	−0·0150
21	1910	1315	1·73	2·77	4·79	10·42	3·00	0·55	389	0·0035	0·0105	−0·024	+0·0135	−0·0173	−0·0038	−0·0210
21a	1910	1275	1·62	2·77	4·49	11·15	3·00	0·53	365	0·0030	0·0090	−0·024	+0·0150	−0·0165	−0·0015	−0·0180

The value of β_0, which comes into this relationship, was determined from Fig. 4 for the values of $q_{t.pen}/\delta^2$ and $\xi=k/\delta$ corresponding to each specimen. The values of the angle γ_{11}, γ_{21}, $\theta_{(1+2)}$, $\gamma_{1(1+2)}$ and $\gamma_{2(1+2)}$ were determined from equations (1), (2), (3), (4) and (5), while it was assumed that $\omega_1=\omega_2=0{\cdot}024$; $\theta_1=\theta_2$; and $\theta_{(1+2)}=2\theta_1$.

The figures in Tables I and II are plotted in Figs. 6 and 7, which show that the experimental values for the angles γ_1, γ_2 and θ coincide well enough with the theoretical figures except for a weld of 8 mm on a 6 mm thick table. In this case the calculated values were considerably higher than the actual figures. This divergence was governed by the fact that the actual outline of the penetration zone and the temperature distribution in the surrounding metal were more uniform than was assumed in the calculation method for a parabolic penetration zone outline. Therefore the equations which regard the penetration zone outline as a rectangle should be used for flange welds with a leg length more than or almost the same as the plate thickness.

Comparison between Experimental and Theoretical Deformations

The equations already advanced establish not only the general relationships of the angular deformations which occur when depositing a bead on the surface of a plate, but also certain particular relationships concerning the actual conditions of fabrication of fillet flange welds. In fact, when making fillet welds, the dimensions of the fusion zone, and the energy required per unit run, depend on the leg of the fillet weld; therefore simpler relationships may be established for the particular case of the angular deformations in the flanges of **T**- and **H**-sections. However, it is expedient first to be certain that the numerous experimental figures which exist, obtained by various research workers during the fabrication of industrial components, fit in with the general relationships given. For this purpose the figures from the numerous observations made by Tsal'man[2] will be used, computing for them the values of the energy per unit run expended in penetrating the parent metal according to the welding conditions indicated in the article (the calculated figures are given in Table III), and replacing the relationship of the flange deflection to its width f/b by the angle $\theta_{(1+2)}=2(f/b)$. The values of $\theta_{(1+2)}$ are given in Table IV, where all the measurements made by Tsal'man are grouped according to the ratios k/δ. Here, for example, the measurements for every component for which k/δ is between 0·25 and 0·35 are placed in the group for $k/\delta=0{\cdot}3$.

Table III

Welding conditions for Tsal'man's tests

k, mm	I, amps	U, volts	Welding speed v, cm/sec	$\frac{IU}{v}$	η_{pen}	$\frac{2\delta_1}{2\delta_1+\delta_2}$ mean	$q_{t.pen}$	$A'=\frac{q_{t.pen}}{k^2}$
6	625	33	1·000	20,600	0·3	0·75	1120	3120
8	775	33	0·835	30,600	0·3	0·75	1660	2600
10	775	33	0·557	46,000	0·3	0·75	2490	2490

Table IV

Angular deformations from Tsal'man's tests

$\frac{k}{\delta}$, *mean*	*Table width* mm	δ_t, *mm*	k, *mm*	$\frac{k}{\delta}$	$\frac{q_{t.pen}}{\delta^2}$	$\theta_{(1+2)}=2\frac{f}{b}$	$\theta_{(1+2)}$ *calculated for* $\frac{k}{\delta}$ *mean*	*Symbols in Fig. 8*
	320	32	6	0·19	110	0·0062		
0·20	410	32	6	0·19	110	0·0072	0·0050	●
	410	32	8	0·25	162	0·0120		
	320	24	8	0·33	288	0·0220		
	320	32	10	0·31	244	0·0124		
	410	20	6	0·30	280	0·0244		
0·30	410	24	8	0·33	288	0·0210	0·0150	×
	410	24	8	0·33	288	0·0210		
	410	32	10	0·31	244	0·0170		
	600	24	8	0·33	288	0·0200		
	210	16	6	0·37	437	0·0320		
	210	20	8	0·40	416	0·0316		
	360	14	6	0·43	571	0·0344		
	320	16	6	0·37	437	0·0312		
0·40	300	20	8	0·40	415	0·0344	0·0310	○
	310	20	8	0·40	415	0·0318		
	480	22	8	0·36	344	0·0236		
	600	20	8	0·40	415	0·0300		
	600	24	10	0·42	432	0·0300		
	210	12	6	0·50	780	0·0428		
	210	16	8	0·50	649	0·0428		
	300	12	6	0·50	780	0·0400		
	350	16	8	0·50	649	0·0400		
0·50	320	20	10	0·50	622	0·0406	0·0430	▲
	350	20	10	0·50	622	0·0400		
	380	16	8	0·50	649	0·0446		
	410	16	8	0·50	649	0·0438		
	410	20	10	0·50	622	0·0390		
	600	20	10	0·50	622	0·0384		
	210	10	6	0·60	1120	0·0496		
	300	10	6	0·60	1120	0·0486		
0·60	350	14	8	0·57	848	0·0512	0·0540	△
	410	10	6	0·60	1120	0·0486		
	410	16	10	0·62	972	0·0560		
0·70	410	12	8	0·66	1155	0·0582	0·0620	■
	600	14	10	0·72	1270	0·0600		
0·80	320	10	8	0·80	1660	0·0750	0·0660	□
	320	12	10	0·83	1730	0·0716		
1·00	300	10	10	1·00	2490	0·1000	0·0575	Ø

Taking into account the fact that the lengths of all the components considerably exceeded the critical value $L_{crit}=9x$, the angular deformations for the flange plates due to each fillet weld should be taken as

$$\beta_e = 3\beta_0$$

and in consequence the full bend of flange plates caused by the two flange welds is

$$\theta_{(1+2)} = 2\beta_e = 6\beta_0 \quad \ldots \quad \ldots \quad \ldots \quad \ldots (13)$$

Values of $\theta_{(1+2)}$ with relation to $q_{t.pen}/\delta^2$ and the ratio $\xi=k/\delta$, which represent values of β_0 (Fig. 4) multiplied by 6, are given in Fig. 8. The experimental values of $\theta_{(1+2)}$ from Table IV are plotted as points on this graph; they are located sufficiently close to the corresponding theoretical curves.

The same data may be represented in a more general form if, instead of $\theta_{(1+2)}=f(q_{t.pen}/\delta^2)$ the relationship of

$$\frac{\theta_{(1+2)}}{\xi} \text{ to } \frac{q_{t.pen}}{\delta^2\xi}$$

is provided. The set of curves will then be replaced by a single curve, and the abscissae will take the form

$$\frac{q_{t.pen}}{\delta^2\xi} = \frac{q_{t.pen}}{\delta k}.$$

A curve of this nature for a penetration zone of parabolic outline is given in Fig. 9 (curve 1). Curve 2 is for a rectangular penetration zone. Experimental points plotted on this graph (from Table IV) are located close to curve 1, and only approach curve 2 at high values of $q_{t.pen}$ or low values of δ.

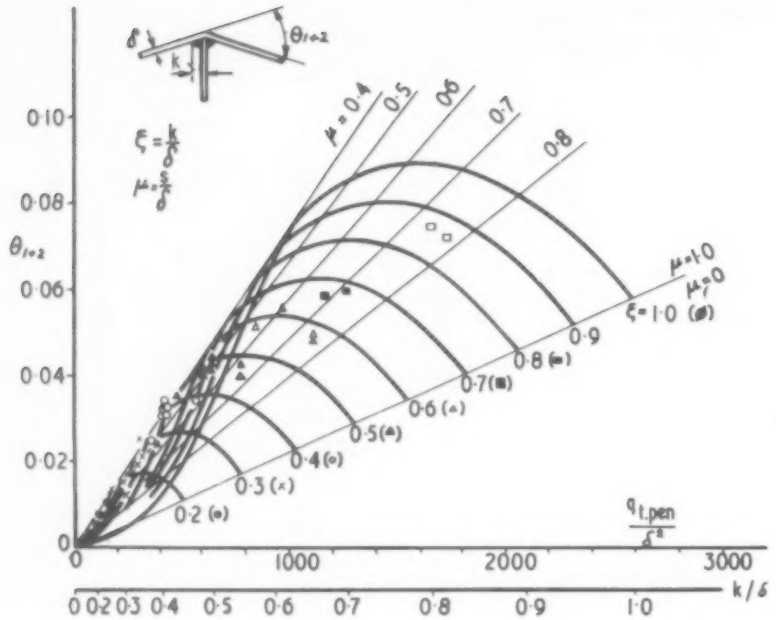
For fillet welds of leg length k, the power required per unit run may be expressed by:[4]

$$q_t = \psi 2350 \frac{U}{\alpha_d} k^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots (14)$$

where ψ = the coefficient of 'fullness' of the weld (for welds with a flush external surface $\psi=1$),

U = the arc voltage,

α_d = the deposition coefficient (taken as a mean 14g/amp.hr for submerged-arc automatic welding).



8—*Comparison of angular deformations of table plates of* T*-sections, calculated and experimental (from Tsal'man)*

In consequence, the power consumed on penetration per unit run may be expressed as:

$$q_{t.pen} = 0{\cdot}43q_t = A'k^2 \qquad .. \quad .. \quad .. \quad (15)$$

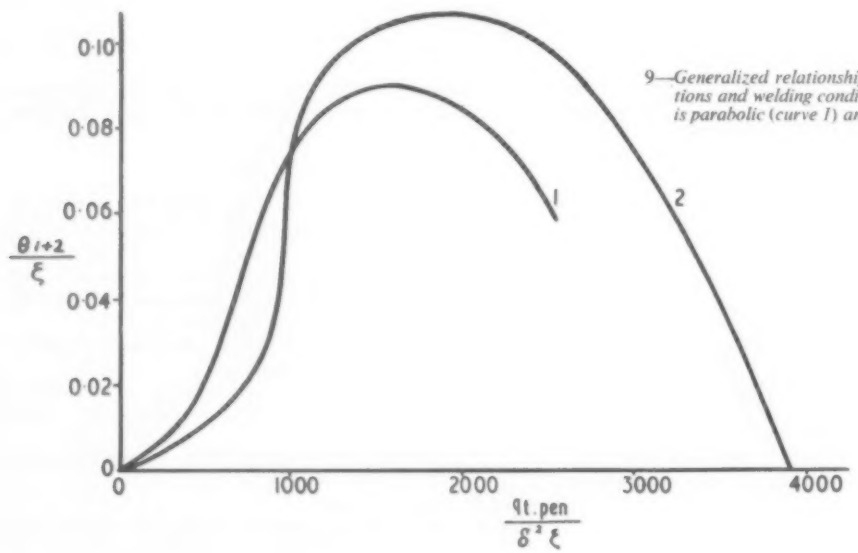
and the scale along the abscissa axis in Fig. 8 may be represented as:

$$\frac{q_{t.pen}}{\delta^2} = \frac{A'k^2}{\delta^2} = A'\left(\frac{k}{\delta}\right)^2$$

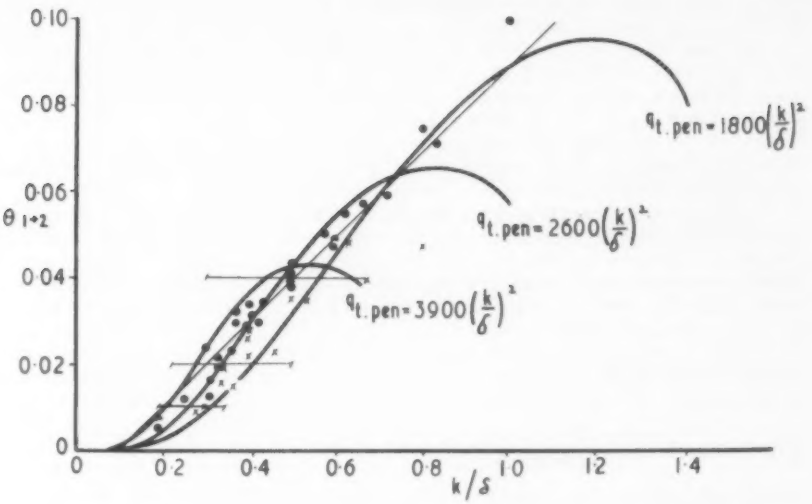
It follows from the above that a completely definite value of the angle $\theta_{(1+2)}$ must correspond to each specific value of k/δ.

Taking as the mean value of A' for the welding conditions given in Table III, a value equal to 2600 cal/cu.cm, Fig. 8 gives the mean calculated values of $\theta_{(1+2)}$ for different values of k/δ.

These mean calculated values are given in the penultimate column of Table IV. If the relationship $\theta_{(1+2)} = f(k/\delta)$ is plotted from these values, it will take the form shown in Fig. 10. The same graph contains curves for other values of the coefficient A'. Thus if $\psi = 1$, $U = 33$ volts and $\alpha_d = 14$ g/amp.hr in equation (14), the coefficient A' proves to be about 1800 cal/cu.cm. The highest value of A' in accordance with the above assumptions[7] is 3900 cal/cu.cm.



9—*Generalized relationship between angular deformations and welding conditions where penetration zone is parabolic (curve 1) and rectangular (curve 2)*



10—*Relationship between angular deformations in flange plates and ratio k/δ*

Points are plotted in Fig. 10 according to Tsal'man's experimental figures, also Bazilevskii's[6] and those of the Scientific Research Institute for Bridges (Table V). In addition, values for the angles $\theta_{(1+2)}$ according to Sakhnovskii's[1] observations are plotted on this graph; he established the following values:

δ_1, *mm*	*k*, *mm*	k/δ	$\theta_{(1+2)}$
12–20	6–8	0·3–0·66	0·4
24–36	8–12	0·22–0·50	0·02
40–50	10–14	0·20–0·35	0·01

Figure 10 makes it clear that the proposed relationships show sufficiently well the true nature of the change occurring in the angular deformations $\theta_{(1+2)}$ of the flange plates of **T**- and **H**-sections with alterations in the basic factors such as the welding conditions, the dimensions of the members being welded, and the dimensions of the flange welds. This permits the amounts of the angular deformations (the mushroom shape) of the flange plates to be sufficiently accurately determined from Fig. 10.

For preliminary approximation the curves in Fig. 10 may be replaced by a straight line, and the angles $\theta_{(1+2)}$ determined from the equation

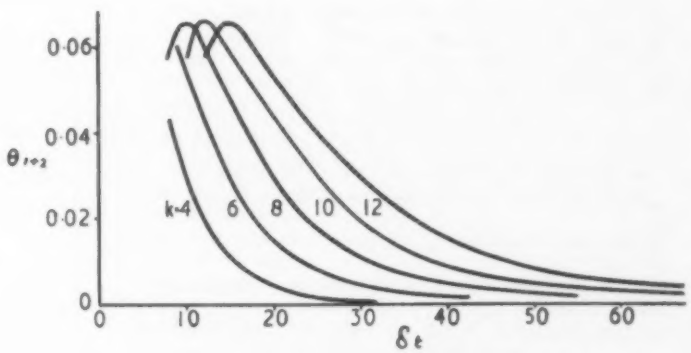
$$\theta_{(1+2)} = 0{\cdot}1\left(\frac{k}{\delta} - 0{\cdot}1\right).$$

Table V

Angular deformations in flange plates

δ_1, *mm*		*k*, *mm*		k/δ	$\theta_{(1+2)}$
A	*B*	*A*	*B*		
10	—	8	—	0·80	0·0472
12	—	8	—	0·67	0·0395
16	—	8	—	0·50	0·0356
—	16	—	10	0·63	0·049
—	20	—	10·5	0·53	0·035
—	24	—	11	0·46	0·023
25	—	10	—	0·40	0·0294
30	—	10	—	0·33	0·0195
30	—	12	—	0·40	0·0266
30	—	12	—	0·40	0·0222
—	32	—	11	0·34	0·016
—	36	—	12	0·33	0·015
40	—	12	—	0·30	0·0106
50	—	14	—	0·28	0·0095

A—Results from Scientific Research Institute for Bridges
B—Results from Bazilevskii[6]



11—*Relationship between angular deformation, table plate thickness, and table plate leg length*

The relationships between the deformation $\theta_{(1+2)}$ and the flange plate thickness are plotted in Fig. 11, for the case where $q_{t.pen}=2600\ (k/\delta)^2$, for different fillet weld legs, to illustrate the influence of flange plate thickness on the magnitude of the angular deformation $\theta_{(1+2)}$. It is clear from these relationships that relatively small fillet weld dimensions result in the marked deformation of quite thick plates. It may be taken, as an approximation, that for 4 mm welds the deformation in flanges less than 400 mm wide is almost zero (<1 mm) only where the plate thickness exceeds 15 mm; for a 6 mm fillet weld leg the plate thickness must exceed 23 mm for the mushroom shape to be negligible. Similarly, for welds whose leg length $k=8$ mm, the plate thickness must exceed 32 mm, for $k=10$ mm it must exceed 40 mm, and for $k=12$ mm it must exceed 50 mm.

Conclusions

The theoretical relationships and the equations given, and also their comparison with deformations measured by various research workers both in the laboratory and in industrial conditions during the fabrication of different types of structure, prove that the flange deformations of welded **H**-beams may be determined sufficiently simply from the graphs in this article, although a variety of factors are concerned.

A knowledge of the relationships between flange plate deformations and the welding conditions, weld dimensions and the dimensions of the sections being welded, enables the individual structural dimensions to be selected deliberately. These include the ratio between flange plate thickness and width for a specific flange cross-section area, and the various parameters in the industrial fabrication of welded structures. For example, the relationships provided are sufficiently convincing proof that it is inexpedient (from the view point of structural deformation) to use fillet welds of excessive leg length. The longitudinal deformation increases proportionally to the square of the leg length, but the angular deformation, for certain ratios of k/δ, increases even more.

In the light of these results certain general requirements of the mechanical properties of weld metal and the heat-affected zone must be examined. To improve the plastic properties of fillet weld metal and metal in the heat-affected zone, welds of large leg lengths should be used. However, increased size of weld results in considerable deformation, which either requires local correction, reducing the plastic properties, or causes additional stresses to arise at the junctions between beam flanges and other members, which may materially reduce structural efficiency. Thus a number of specifications aimed at raising the quality of welded structures may result in the opposite, unless all the consequences of carrying out each specification are taken into account.

Specifications exist, and are still frequently applied to various welded structures and their fabrication without sufficiently detailed analysis of all the circumstances of their fulfilment. These specifications must be reviewed, taking into account all the processes which occur during welding, in particular the conditions of origin of welding deformations. This article reinforces the existing methods of determining welding deformations by calculation, and may thereby simplify the drawing up of rational specifications for the material, the structural shapes and the fabrication of welded structures.

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INTERNATIONAL INSTITUTE OF WELDING

EFFECT OF STORAGE TIME ON THE HYDROGEN CONTENT AND MECHANICAL PROPERTIES OF ARC WELDS MADE WITH COVERED ELECTRODES

By W. Hummitsch

Programme

THE purpose of the investigation was to discover, by means of storage tests, the speed with which the hydrogen content of weld metal deposited by different types of electrode decreases; simple tensile tests were used to complete the measurements.

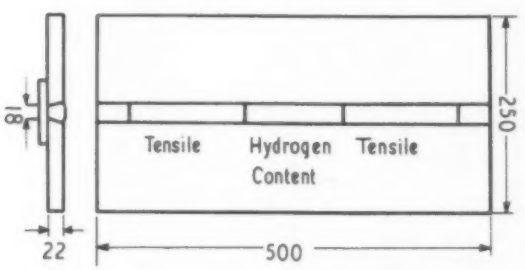
Welding procedure and preparation of test pieces

Seams were welded as shown in Fig. 1. A mild steel 22 mm thick was used. After storage, specimens were taken from the seams; those for the hydrogen tests coming from the middle while the tensile test pieces were taken from the edges. The specimens were prepared a short time before the testing itself took place; they were taken after 4, 12, 24, 48, 96, 480, 960 and 2400 hr, and even, in a later set of investigations, after 3600 and 5100 hr.

Programme tests

Only simple tensile tests were used. The specimen was 10 mm dia., the gauge length for elongation being 50 mm. Two samples were tested each time. The tables and the drawings show the yield points, the tensile strengths, the elongations and the reductions in area in relation to the storage time.

The total hydrogen contents indicate the quantities extracted in vacuum from molten metal at a temperature of 1600°C. In a few specimens the diffusible hydrogen content in the weld metal was determined at 45°C. Moreover, the results of different methods of determining the hydrogen contents were compared (Table A_3). (Hot extraction in vacuum at 1600°C., 1000°C. and 650°C. and determination of the content of diffusible hydrogen at 45°C.)



1—*Preparation of mild steel specimen*

THE ELECTRODES

The following types of electrodes were used:

(1) Electrodes with an acid type coating. Core diameter 4 and 5 mm.

(2) *a*—Electrodes with a rutile type coating. Fluid slag. Core diameter 4 mm.
b—Electrodes with a rutile type coating. Viscous slag. Core diameter 4 mm.

(3) Electrodes with a basic type coating. (Lime fluorspar slag). Core diameter 4 mm.

The analysis of the weld metal was as follows:

Type of coating	*C* %	*Si* %	*Mn* %	*P* %	*S* %	N_2 %
Acid	0·09	0·07	0·41	0·029	0·020	0·016
Rutile fluid	0·08	0·20	0·52	0·026	0·023	0·013
Rutile viscous	0·05	0·36	0·51	0·023	0·029	0·028
Basic	0·07	0·45	0·82	0·015	0·018	0·008

Results

Each of the figures on the graphs indicates the mean value of two tests.

A distinction must be made between diffusible hydrogen and total hydrogen: the diffusible hydrogen was measured at a temperature of +45°C., the total hydrogen by vacuum extraction at 1600°C.

Diffusible hydrogen (Fig. E and Tab'e E)

Diffusible hydrogen in weld metal, determined at a temperature of +45°C. in relation to the time of storage. In this particular case, measurements were made immediately after welding, 2 hr and 24 hr afterwards.

In Table E and Fig. E:

A_1 represents weld metal from electrodes with acid coating,

B_1 represents weld metal from electrodes with rutile coating, fluid slag.

C_1 represents weld metal from electrodes with rutile coating, viscous slag,

D_1 represents weld metal from electrodes with basic coating.

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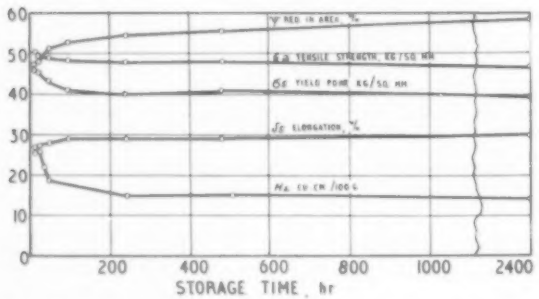
Table A_1

Results of tensile tests in relation to storage time

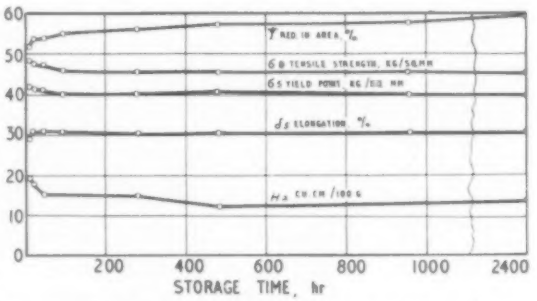
Acid type of coating; Dia. of core 4 mm; Dia. of coating 6·4 mm; Moisture content in coating (tested at 150°C.) 0·28 to 0·39%

Storage Time, hr	*Yield Point, kg/sq.mm*	*Tensile Strength kg/sq.mm*	*Elongation (l=5.d), %*	*Reduction in Area, %*	*Total Hydrogen Content, cu.cm/100 g*	*Number of Fish eyes*	*Area of fish eyes in relation to the cross-section of 78·5sq.mm %*
4	48·7	52·8	23·5	45·3	28·0 31·0	2	0·24
	49·3	53·7	22·8	43·0	29·0	2	0·18
12	46·8	50·3	26·4	48·0	27 26·5	1	0·15
	46·2	50·9	25·5	46·7	28	4	0·48
24	45·7	49·5	27·7	48·7	24 28	2	0·275
	44·9	49·0	27·0	47·9	26·5	3	0·425
48	43·0	48·8	28·4	52·0		1	0·16
	43·0	48·7	27·6	50·6	17·8 18·0	3	0·376
96	41·7	48·7	28·6	53·0			
	40·9	47·9	28·2	52·0			
240	39·8	47·6	29·0	54·1	14·4 15·0	0	0
	40·4	48·4	29·1	54·5	15·6 14·3	1	0·08
480	40·4	47·3	29·8	56·0	15·0 15·5	1	0·41
	41·0	48·3	28·6	55·3		1	0·38
960	39·2	46·9	29·6	56·6		0	0
	40·8	47·7	29·0	56·0		2	0·74
2400	39·7	46·7	29·8	58·2	12·9 15·8	1	0·07
	39·0	46·3	30·4	58·0	14·3 13·0	1	0·24

The highest temperature of the seam was 180°C.



A_1—*Tensile tests in relation to storage time: Acid type of coating*



A_2—*Tensile tests in relation to storage time: Acid type of coating*

Table A_2

Results of tensile tests in relation to storage time

Acid type of coating; Dia. of core 5 mm; Dia. of coating 8·0 mm; Moisture content in coating (tested at 150°C.) 0·35 to 0·46%

Storage Time, hr	*Yield Point, kg/sq.mm*	*Tensile Strength, kg/sq.mm*	*Elongation (l=5.d), %*	*Reduction in Area, %*	*Total Hydrogen Content, cu.cm/100 g*	*Number of Fish eyes*	*Area of fish eyes in relation to the cross-section of 78·5 sq.mm, %*
12	42·8	48·4	28·6	50·7	18·7 19·5	3	0·35
	42·2	47·6	29·4	52·5	19·2	1	0·18
24	41·7	47·5	29·8	52·9	17·3 18·0	4	1·10
	40·9	46·9	30·6	53·9		1	0·05
48	40·3	46·2	30·5	53·6	13·3 12·6	2	0·22
	40·7	47·0	30·9	54·6	14·1 16·0	2	0·18
96	39·8	45·7	30·0	54·2			
	39·8	45·0	31·0	55·0			
240	40·0	45·0	30·6	57·0	14·3 14·4	2	0·18
	40·4	45·8	30·0	55·0	15·2 15·9	2	0·18
480	40·0	45·1	31·3	59·6	12·0	2	0·52
	41·0	46·0	29·4	54·8		6	1·60
960	41·0	45·8	30·6	58·3		0	0
	39·0	44·6	29·8	57·4		2	0·14
2400	39·8	45·0	30·3	59·0	13·9 14·3	1	0·06
	39·8	44·8	31·0	59·8	13·5	0	0

Table A_2

Hydrogen contents, obtained by different procedures, in weld metal

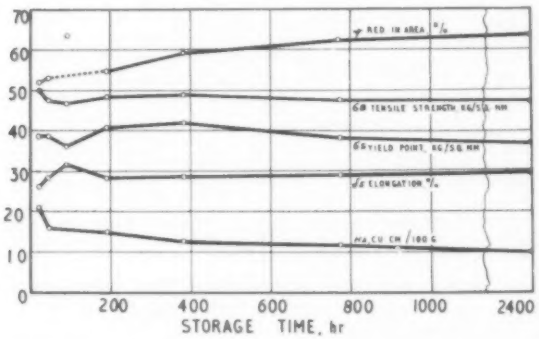
Acid type of coating; Dia. of core 4 mm; Dia. of coating 6·4 mm; Moisture contents in coating (tested at 150°C.) 0·32 to 0·39%. Diffusible hydrogen 120 sec. after welding determined at 45°C., was 27·3, 25·8, 29·8 cu.cm/100 g.

Storage Time, hr	*Total H_2 1600°C. cu.cm/100 g*		*H_2 1000°C. cu.cm/100 g*		*H_2 650°C. cu.cm/100 g*		*H_2 45°C. cu.cm/100 g*		*Number of Fish eyes*	*Area of fish eyes in relation to the cross-section of 78·5 sq.mm., %*
4	29·0	31·0			21·0	19·5	11·3	12·7	3	0·26
24	28·0	23·5	24·5	21·3			5·8	6·2	4	0·34
96	16·7	19·2			12·3	11·8	2·3	1·8	2	0·53
2400	12·9	11·7	9·5	9·0					1	0·16
3600	8·2	8·7			6·2	6·4			0	0
5100	7·9	8·3	7·2	6·4	5·8	6·2			0	0

Tensile tests on the weld metal

Storage Time, hr	*Yield Point, kg/sq.mm*	*Tensile Strength, kg/sq.mm*	*Elongation, ($l=5.d$), %*	*Reduction in Area, %*
4	49·8	54·2	21·3	43·2
24	46·8	51·3	23·2	44·5
96	42·7	48·2	24·8	42·3
3600	39·2	46·3	31·4	58·2
5100	39·7	46·7	30·3	58·8

Temperature during storage, 12° to 22°C.



B—*Tensile tests in relation to storage time: Rutile type of coating (fluid slag)*

After 2 hr, the amount of diffusible hydrogen (Fig. E) decreased to less than half of the original quantity. After 12 hr it amounted to:

- —14 cu.cm/100 g : electrodes with an acid coating.
- —10 cu.cm/100 g : electrodes rutile type coating, fluid slag.
- — 9 cu.cm/100 g : electrodes rutile coating, viscous slag.
- — 2 cu.cm/100 g : electrodes basic type coating (low hydrogen type).

Total contents of hydrogen (Tables and Drawings A to D)

All tables and drawings show the total hydrogen content in the weld metal. In addition, the tables show the number of fish eyes and their total area in relation to the section of the tensile test bar with a diameter of 10 mm (78·5 sq.mm).

Table B

Results of tensile tests in relation to storage time

Rutile type of coating (fluid slag); Dia. of core 4 mm; Dia. of coating 6·4 mm; Moisture content in coating (tested at 105°C.) 0·33 and 0·46%. (Measuring length $l=50$ mm, $d=10$ mm)

Storage Time, hr	*Yield Point, kg/sq.mm*	*Tensile Strength, kg/sq.mm*	*Elongation, %*	*Reduction in Area, %*	*Total Hydrogen Contents, cu.cm/100 g*		*Number of Fish eyes*	*Area of fish eyes in relation to the cross-section of 78·5 sq.mm, %*
4	44·2	52·9	23·8	46·0	27·0	23·0	2	0·32
	45·8	54·8	24·2	48·0	26·0		1	0·23
24	39·3	50·0	26·4	54·0	22·0	21·0	0	—
	38·9	49·1	26·0	50·0	21·6		0	—
48	39·8	48·0	29·0	54·0	15·3	16·5	0	—
	37·6	47·1	28·0	50·0	15·8		1	0·71
96	36·9	47·8	31·6	64·0	14·3	15·4	0	—
	35·7	46·5	31·6	64·0	14·9		0	—
192	40·7	49·0	28·0	48·2	12·7		1	1·00
	42·6	47·7	28·8	63·0			0	—
384	41·4	47·7	28·0	61·0	12·2	10·9	0	—
	43·3	49·6	29·2	56·5			0	—
768	38·2	47·7	30·0	61·6	12·3	10·9	0	—
	37·5	48·0	27·4	63·5			0	—
2400	37·6	47·3	30·0	66·0	10·9	9·5	0	—
	37·0	46·7	29·6	62·0			0	—

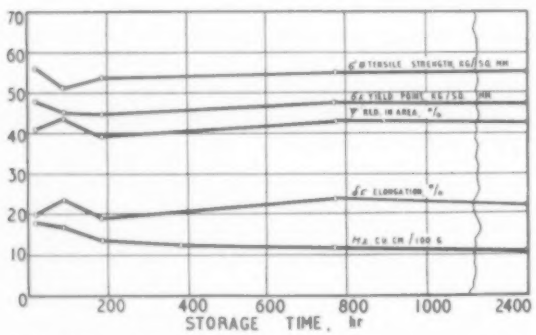
The highest temperature of the seam was 160°C.

Table C

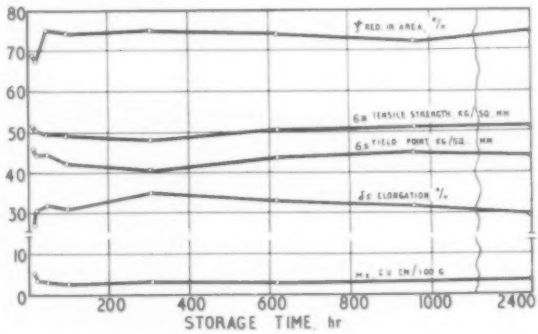
Results of tensile tests in relation to storage time

Rutile type of coating (viscous slag); Dia. of core 4 mm; Dia. of coating 5·6 mm; Moisture content in coating (tested at 105°C.) 0·84% and 1·02%. (Measuring length $l = 50$ mm; $d = 10$ mm)

Storage Time, hr	*Yield Point, kg/sq.mm*	*Tensile Strength, kg/sq.mm*	*Elongation, %*	*Reduction in Area, %*	*Total Hydrogen Content, cu.cm/100 g*		*Number of Fish eyes*	*Area of fish eyes in relation to the cross-section of 78·5 sq.mm, %*
24	47·8	55·2	18·6	42·3	20·2	19·5	1	0·72
	48·3	56·1	17·9	39·0	19·7		2	1·10
96	44·6	51·6	24·8	42·2	16·2	17·0	3	8·7
	45·8	51·0	23·0	44·8	16·8		0	—
192	43·8	53·5	14·8	27·9	15·4	12·6	3	0·8
	45·2	53·5	22·6	49·7	12·0		0	—
384					12·6	12·3		
					11·2			
768	48·4	55·4	21·8	42·3	12·2	11·2	2	5·8
	47·7	55·5	24·8	43·6	10·7		2	2·7
2400	47·7	54·7	21·8	43·6	12·3	10·9	2	2·8
	46·5	55·6	22·7	43·5	10·5		1	0·72



C—*Tensile tests in relation to storage time: Rutile type of coating (viscous slag)*



D—*Tensile tests in relation to storage time: Basic type of coating*

Table D

Results of tensile tests in relation to storage time

Basic type of coating; Dia. of core 4 mm; Dia. of coating 6·4 mm; Moisture content in coating (tested at 1000°C.) 0·46% and 0·41%; (Measuring length $l = 50$ mm, $d = 10$ mm)

Storage Time, hr	*Yield Point, kg/sq.mm*	*Tensile Strength, kg/sq.mm*	*Elongation, ($l = 5.d$), %*	*Reduction in Area, %*	*Total Hydrogen Content, cu.cm/100 g*		*Number of Fish eyes*	*Area of fish eyes in relation to the cross-section of 78·5 sq.mm, %*
4	47·8	52·8	27·5	65·3	6·3	5·6	1	0·28
	48·7	53·9	27·8	63·0	5·7		1	0·23
12	44·8	50·0	28·0	70·5	5·5	5·1	1	0·23
	47·1	52·5	26·0	67·3	5·1	5·6	1	0·29
24	44·5	50·0	32·0	72·8	3·3	2·9	0	—
	44·7	50·4	30·0	62·7	3·8		1	1·90
48	43·8	49·8	30·6	74·8	3·1	2·8	0	—
	44·7	49·4	34·0	75·8			0	—
96	42·2	49·0	31·0	73·7	3·5	2·2	0	—
	42·7	50·2	31·0	75·0	2·1		0	—
312	39·7	48·0	36·0	75·0	3·7	2·3	0	—
	40·7	47·7	34·4	75·0			0	—
624	44·0	50·8	32·6	73·8	3·1	2·8	0	—
	44·0	50·8	32·6	73·8			0	—
960	43·4	50·3	31·8	70·6			0	—
	46·0	51·2	31·0	72·8			0	—
2400	44·4	51·0	28·3	73·8	3·0	4·3	1	0·15
	42·6	50·7	30·0	75·0	2·8	3·1	0	—

The highest temperature of the seam was 170°C.

Table E

Diffusible hydrogen content in the weld metal

Determinated at +45°C.; Hydrogen content cu.cm/100 g.

Type of Electrode	*After 120 sec*		*2 hr*		*24 hr*	
A_1 acid	28·4	24·8	14·8	16·3	14·0	12·8
	29·9	24·9	18·2	19·0	10·0	
B rutile heavy coated fluid	25·0	21·0	11·0	11·8	9·7	8·7
	26·0	21·6	10·5	11·6	6·9	
C rutile viscous	23·2	14·4	11·3	10·0	7·6	7·2
	19·7	15·6	9·1	10·8	6·5	
D basic	3·2	1·9	0·70	1·1	0·9	0·5
	4·1	1·9	0·80	1·0	0·8	

Table F

Interpass-temperatures of the seam (see Table A_1)

Plate, 500 × 250 × 22 mm; Groove profile, single V, gap 18 mm; 4 mm dia. electrode with acid type of coating; d.c. 180 amp.

Number of Layers	*Time*	*Temperature °C.*					
		Of the seam			*Of the steel near the seam*		
	hr/min	*Start*	*Middle*	*End*	*Start*	*Middle*	*End*
1 root	7^{53}	45	65	80	30	40	50
2 root	8^{22}	85	110	110	80	90	90
3 root	8^{50}	100	120	150	110	115	125
1 layer	9^{24}	110	120	130	115	130	150
2 layer	9^{56}	120	145	180	135	160	160
3 layer	10^{30}	105	115	135	110	120	130
4 layer	11^{17}	120	145	180	125	140	165
5 layer	12^{01}	120	140	160	105	120	140
6 layer	12^{33}	125	135	150	120	140	150
7 layer	13^{06}	120	125	135	110	125	145
8 layer	13^{42}	100	115	140	120	125	135
9 layer	13^{58}	115	125	130	110	120	130
10 layer	14^{15}	135	140	145	130	135	140
11 layer	14^{36}	140	145	155	130	140	145
—	17^{30}	30	30	30	30	30	30

Total time, 416 min; Welding time, 44 min 33 sec.
The highest temperature of the seam was 180°C.
Three hours after the end of welding the temperature of the seam was 30°C.

Electrodes with an acid type coating (Tables and Drawings A_1 and A_2)

After a storage time of 2400 hr, the hydrogen content decreased to half the initial value (12 hr). Yield point and tensile strength decreased with the time of storage, while elongation and reduction in area increased. There were fewer fish eyes after a storage time of 2400 hours.

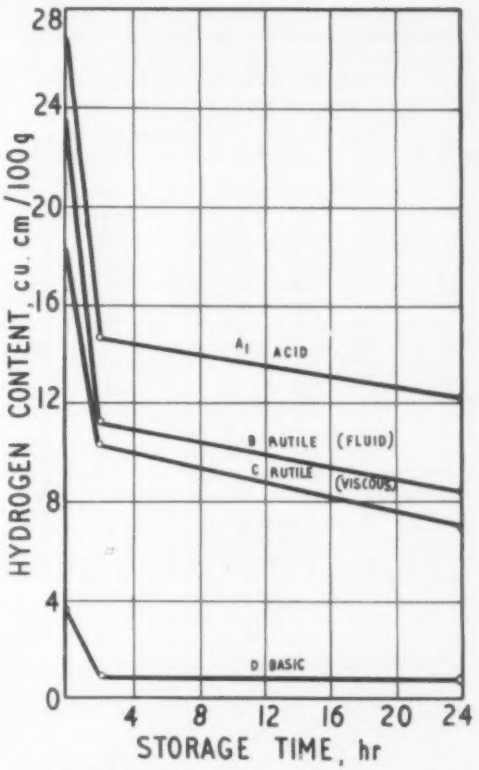
A further series of tests with storage times of up to 5100 hr was carried out. The results are given in Table A_3. After more than 2400 hr no fish eyes were to be observed. The total hydrogen content (measured at 1600°C.) of the weld metal was 8·3 cu.cm/100 g, after a time of 5100 hr.

Electrodes with an acid type of coating (Tables and Drawings B and C)

B Electrodes with a rutile type of coating, 4 mm dia., fluid slag.

C Electrodes with a rutile type of coating, 4 mm dia., viscous slag.

After a storage time of 2400 hr the total hydrogen content fell to half of the initial value (12 hr).



E—*Diffusible hydrogen in weld metal: Temperature 45°C.*

There was little change in yield point, tensile strength, elongation and reduction in area.

After 2400 hr there were no fish eyes with electrode B and a few with electrode C.

Electrodes with a basic coating (Table D and Drawing D)

The length of the storage time had practically no effect on the results of tensile tests. The total contents of hydrogen in the weld metal were low. Most fractures did not show fish eyes.

Interpass-Temperatures of the Seams

The highest interpass temperatures of the seams were 160°C. to 180°C. for the four types of electrode tested. (Tables F to H.)

Conclusions

The dissolved hydrogen in the weld metal escapes during storage until it has reached a minimum value. A storage time of 2400 hr and more was not evidently always sufficient to eliminate all fish eyes. It is difficult to see any definite correlation between hydrogen content and the area covered by fish eyes, but no doubt other factors exert an influence.

Nevertheless, from the results of the tensile tests it is possible to see the effects of dissolved hydrogen on the weld metal. These results vary, the elongation values usually increasing with the time of storage.

Table G

Interpass-temperatures of the seam (see Table B)

Plate, 500 × 250 × 22 mm; Groove profile, single V, gap 18 mm; 4 mm dia. electrode with rutile type of coating; d.c. 180 amp.

Number of Layers	Time	Temperature °C. Of the seam			Of the steel near the seam		
	hr/min	Start	Middle	End	Start	Middle	End
1 root	8^{03}	50	65	75	65	85	105
2 root	8^{30}	80	95	120	80	90	105
3 root	9^{00}	100	115	135	110	115	135
1 layer	9^{34}	105	105	120	110	110	125
2 layer	10^{30}	100	115	150	110	120	170
3 layer	11^{09}	100	105	130	120	120	135
4 layer	11^{36}	120	125	150	135	135	135
5 layer	12^{10}	110	120	140	110	110	120
6 layer	12^{48}	115	140	150	115	140	155
7 layer	13^{16}	100	120	135	110	125	140
8 layer	13^{51}	100	120	120	105	110	125
9 layer	14^{07}	115	130	135	110	120	125
10 layer	14^{22}	125	140	155	120	135	150
11 layer	14^{45}	125	145	160	130	145	160
12 layer	15^{26}	150	155	160	150	160	160
—	17^{26}	45	45	45	45	45	45

Total time, 455 min; Welding time, 48 min 2 sec.
The highest temperature of the seam was 160°C.
Two hours after the end of welding the temperature of the seam was 45°C.

Table H

Interpass-temperatures of the seam (see Table D)

Plate, 500 × 250 × 22 mm; Groove profile, single V, gap 18 mm; 4 mm dia. electrode with basic type of coating; d.c. 175 amp.

Number of Layers	Time	Temperature °C. Of the seam			Of the steel near the seam		
	hr/min	Start	Middle	End	Start	Middle	End
1 root	8^{12}	60	85	145	80	95	110
2 root	8^{40}	90	100	125	100	120	150
1 layer	9^{15}	105	125	150	130	145	180
2 layer	9^{45}	110	125	160	125	140	145
3 layer	10^{41}	105	115	150	105	125	145
4 layer	11^{08}	105	125	135	115	130	145
5 layer	11^{38}	120	135	150	115	130	145
6 layer	12^{25}	105	130	135	105	125	130
7 layer	12^{56}	135	145	170	135	145	180
8 layer	13^{32}	130	145	170	120	135	155
—	17^{30}	30	30	30	30	30	30

Total time, 332 min; Welding time, 55 min 19 sec.
The highest temperature of the seam was 170°C
Four hours after the end of welding the temperature of the seam was 30°C.

The welds made with electrodes with an acid type of coating (Fig. A_1–A_2, Tables A_1–A_2) show clearly the effects of dissolved hydrogen. Though less marked, they are also to be seen in the welds made with electrodes with a rutile type of coating, where the slag is fluid (Fig. B, Table B), but if the slag is viscous no effect of this kind is to be observed (Fig. C, Table C).

With welds made with electrodes with a basic coating, there is hardly any change in the values of the tensile properties during the time of storage. The total hydrogen content of the deposited metal is low, even immediately after welding (Fig. D, Table C). Most of the fractures in the tensile tests do not reveal fish eyes

CZECHOSLOVAKIAN WELDING CONGRESS

Reported by Dr. J. Krotkovsky, of the Welding Research Institute of Bratislava

The Eighth International Welding Congress, organized by the Slovak Academy of Science, the Welding Research Institute, and the Welding Section of the Czechoslovak Scientific-Technical Society, was held in Bratislava, Czechoslovakia, on 7th–8th October 1958. There was an attendance of 110 delegates from numerous works, research organizations, and other institutions, both from Czechoslovakia and from other countries (Germany, Austria, Belgium, Poland, Hungary, and the U.S.S.R.).

The main theme of the Congress was *Welding in Metallurgy* – a limited branch of welding – yet the lively discussion after most of the papers showed the wide range of applications that are yet possible.

Repair and maintenance

In the main lecture, Professor Ing. Dr. Jozef Čabelka, Director of the Welding Research Institute in Bratislava, demonstrated with some characteristic examples how metallurgical production could be efficiently assisted by welding, in the maintenance and repair of mill equipment, starting from ore dressing up to the production of large and heavy castings and forgings. The lecturer explained the causes of cracking in Krupp-Renn revolving kilns, and suggested a method of repair. He also recommended for the construction of such furnaces the selection of material of good weldability and indicated measures to be taken against carburization of the coating in places where the lining had fallen out. Further, he recommended for blast-furnace linings the use of good weldable and not ageing steels which would safely resist thermal stress.

Iron chills, as applied in steel production, can be repaired when damaged by the aid of welding, and thus their service life could be extended. Welding could also be applied to an even greater extent to the surfacing of rolls for semi-finished products, sections, and sheets. For restoring the working surface of rolls the technique of

automatic welding under flux had been developed and had proved to be efficient and economic in practice.

An example of welding technology that directly affects metal production is the process of joining brass strips into larger coils by the argon-shielded electric-arc welding method, using a unit developed in the Bratislava Welding Research Institute, which complies with the requirements of the metallurgical industry in regard to speed and economy.

The most serious metallurgical problem obstructing the development of large metallurgical plant is the production of heavy forgings, which cannot be made with uniform properties throughout. It is here that the welder has given great assistance to the metallurgist with the introduction of a new welding technique – the electro-slag welding process – which has all the prerequisites for solving even complicated metallurgical products, for it allows the heaviest sections and thicknesses to be joined. The process will enable engineers to design and construct, especially for power plants, very large units from numbers of smaller parts, which are easier to manage.

By these characteristic examples the author showed the important part welding will take in the further development of metallurgy, not only in the technical sense of mechanization and automation, but also economically, leading to higher production and to cutting of costs.

Ceramic fluxes

Then followed a paper presented by Professor Dr. Techn. sc. K. V. Ljubavský on *New Ceramic Fluxes for Arc Welding*. The lecturer indicated the characteristics and properties of the new type of fluxes developed in the CNIITMAŠ in Moscow. These fluxes have no oxidizing effect, can be sintered at relatively low temperatures, and their 'plasticity' can be increased by adding pure Al_2O_3 or some other oxide with a high melting point. Finally, he emphasized their technological advantages compared with the normal fluxes and their suitability for welding pearlitic steels, for the weld metal deposited with these fluxes gives a relatively high impact value.

Roll repairs

A further paper was given by Ing. K. Sniegoń, of the Instytut Spawalnictwa, Gliwice (Welding Institute of Gliwice, Poland), who dealt with the subject *Reconditioning of Metallurgical Rolls, Travelling Crane Wheels, and Forging Dies by Welding*. He showed how particular problems could be solved, partly by the use of alloyed filler metal, and partly by the aid of surface flame hardening. He gave examples of the costs of the repairs of rolls and demonstrated the economics of the technique.

Porosity

The afternoon programme of the Congress began with a lecture by Professor Erdmann-Jesnitzer of the Mining Academy in Freiberg (Germany) on the *Influence of the Magnetic Field on Porosity and Mechanical Properties of Weld Metal*. In the theoretical part of his lecture the author indicated the change of some properties of steel in the region of the Curie-point, where it loses its ferromagnetism and where the maximum carburizing occurs, and also where the depth of carburization of the surface is at its greatest in the presence of hydrogen.

He described an experimental research carried out to verify a certain patent specification, which stated that the porosity of weld metal could be prevented by the influence of a magnetic field. The result of the tests was negative, for the mechanical properties of the welds and the inclination to porosity did not change. However, with a magnetic field of 800 oersteds there was a relative maximum of notch toughness and a chain grouping of pores vertical to the notch.

In conclusion, the lecturer indicated the causes and the mechanism of pore formation in welds, and observed that gases were dia-magnetic and could be influenced by a magnetic field.

Electro-slag welding

The last lecture of the first day was a paper by Ing. Lombardini and Ing. Zeke of the Bratislava Welding Research Institute, on the *Properties of Electro-slag Welded Joints*. The authors described the advantages of this new welding technique – its efficiency and the possibility of welding not only thick material but even hardenable metals of poor weldability – because of the cooling rate, which is the least of all welding methods used, and the resulting favourable thermal balance.

Brittle fracture

The second day of the Congress began with a paper by the Belgian delegate, Mr. O. L. Bihet, of the Central Institute of Metallurgical Research in Liège, on *Belgian Research on Brittle-Fracture-Resisting Structural Steels*. He presented very interesting results of tests specially designed to determine the tendency of structural steels to brittle fracture. Large cruciform specimens were tested in special equipment which allowed test loads to be applied simultaneously in two directions. The character of the fractures of these specimens enabled the tendency to brittle fracture and the weldability of the steels to be evaluated. The tests related mainly to Thomas steel, considered generally to be not suitable for welding, but which the author declared to be at least of as good a quality as open-hearth steel if the nitrogen is stabilized by aluminium, and if the phosphorus is at the optimum limit. He placed converter steel in the class C and D quality, according to the International Institute of Welding.

Oxygen cutting

A further contribution was a paper by the Czechoslovak delegates, Ing. Dubna and L. Kulhánek of the Research Institute for Welding Machines and Welding Technology in Chotěboř, which dealt with *Metal Oxy-Cutting and Machining*. This was a survey of the applications of the oxy-acetylene process for cutting, machining, and surface finishing of metals, mainly carbon and alloy steels, white, grey and malleable cast iron, and non-ferrous metals. The paper described the equipment developed for these purposes in the Research Institute, and indicated further possibilities of applying oxygen to metal working.

The last paper, presented by Ing. G. Kürschner of the Central Institute of Welding, Halle (Germany), dealt with a similar theme, the *State of Development of Apparatus and Techniques of Oxy-Acetylene Cutting in Metallurgy*. The author described new types of cutting devices which are more applicable to metallurgy than the existing types. They are designed on the multi-jet ring-type principle and are economic and simply maintained.

The Austrian delegate, Professor Ing. Dr. Rapatz, concluded the proceedings of the Congress with an appreciation of the sincere fellowship it had evoked and of the great interest that had been shown, during the discussions, in the welding techniques and problems which had been presented

Welding
RESEARCH

B.W.R.A. REPORT

Notch Ductility of Mild-Steel Weld Metal

By F. Watkinson, B.SC. (ENG.)

The paper gives the results of some work carried out for the B.W.R.A. to provide the means for comparing the brittle fracture tendency of different mild-steel weld metals, among themselves and with plate materials in common use. The results provide Charpy V-notch impact data for positional welds made with electrodes from Classes 1, 3, and 6. The normal tensile data for these deposits are given, as well as hardness surveys, chemical analyses, and the results of micro-fissure surveys.

The superior transition characteristics of the Class 1 weld metal is offset by its much higher fissure density, compared with the Class 6 weld metal. Attention is drawn to this and other factors involved when considering the problem of brittle fracture in welded platework structures.

Introduction

THE work described in this report arose from extensive recent researches on brittle fracture. Most of these have been concerned mainly with the behaviour of the parent steel, the welding being regarded as merely one of the influencing factors. It was felt that some attention to the behaviour of the weld metal itself would be justified, and accordingly a programme was carried out with the Association's support, at the Battersea College of Technology under the guidance of a panel of the B.6 (FE.19) Committee.

Considerable thought was given to the choice of a suitable test to reflect the notch ductility of the weld metal, since many different tests were in use for the assessment of this property in parent steel, and their interpretation was controversial. Owing to the small volumes involved in the testing of weld metal, it became clear that the Charpy V-notch impact test was the most practical, and this was adopted, in spite of its limitations. Notch ductility is not the only factor to be considered in assessing weld metal, and it may indeed be outweighed by considerations such as the soundness of the metal itself, and its liability to microfissuring and cracking, as well as the ordinary tensile properties, including yield point and elongation.

The available resources did not permit a full statistical investigation of the many variables involved, such as the type and make of electrode, welding procedures, effects of thickness, preheating, post-heating, stress relief, etc.; it was felt, nevertheless, that the investigation would be worthwhile in providing some fresh general information, and the results given in this report should be looked at in this light.

There is a real danger, however, that the presentation of such results may lead to some misinterpretation, and that unjustifiable comparisons may be drawn. In particular, it might be inferred from the results of the Charpy tests that of the three types of electrode used, the basic (low-hydrogen) type is the least suitable for structures in which brittle fracture may occur. Such an inference would ignore the other considerations mentioned above.

It might also be inferred that the impact values found are representative of the types of electrode mentioned. This would be unjustifiable in view of the small numbers tested. The differences found are fairly small, and might well have been reversed by a different arbitrary choice of the electrodes available at the time when the tests were carried out. Electrodes are subject to continuous improvement, so that an order of merit is unlikely to remain valid for any length of time. Certain

Report FE.19/66/58 of the B.W.R.A., circulated to members in September, 1958.

Mr. Watkinson is a Research Officer with the Association.

current brands of basic electrodes give better results than those reported.

Programme of Investigation

The programme of work was agreed upon as a result of an original proposal by Mr. E. P. S. Gardner that the notch ductility of weld metal in joints in large platework structures, such as storage tanks, should be investigated. In particular, it was proposed that attention should be given to the relative characteristics of weld metal deposited by basic, cellulosic, and rutile electrodes, and also to the influence of welding position.

A detailed programme, guided by a panel of the FE.19 Committee, was therefore drawn up on these lines, using the Charpy **V**-notch impact test as the main notch-ductility test.

Three types of electrodes were to be used—rutile, cellulosic, and basic or lime-fluoride. Two brands of each were specified, and purchase was through normal channels. They were stored as recommended by their manufacturers, except for the lime-fluoride electrodes which were stored for 1 hr with normal air circulation, at 150°–250°C., before use.

They were to be used in the four welding positions, downhand, overhead, vertical, and horizontal-vertical.

The agreed welding procedure was to make welds 32 in. long, between 1 in. plates, with a single-**U** joint. Details of the edge preparations were:

Angle of bevel	15°
Root radius	$\frac{1}{4}$ in.
Root face	$\frac{1}{4}$ in.
Root gap	0

During welding the plates were unrestrained, and an interpass temperature of 17°±3°C. was observed. After approximately $\frac{3}{8}$ in. depth of joint had been deposited, the weld was back-chipped to solid weld metal and back-welded before completion of the joint.

It was arranged that two contractors, '*A*' and '*B*', would produce duplicate sets of welds, and that there would be a minimum period of 8 weeks between welding and testing.

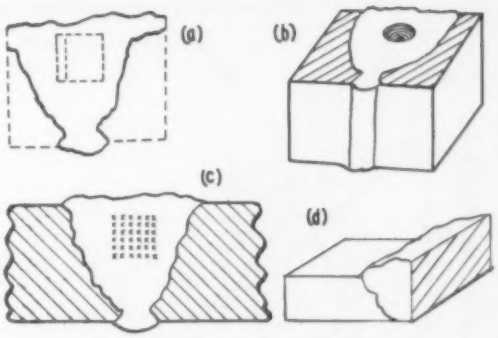
From these welds, at least eight Charpy test pieces and one tensile test piece were to be machined. The former were of the following dimensions:

Length	55 mm
Square cross-section	10×10 mm
Notch depth	2 mm
Angle of notch	45°
Root radius of notch	0·25 mm

They were to be machined from the line of the weld, with the notch normal to the plate surface (Fig. 1*a*). The tensile piece, also machined from the line of the weld was to be a sub-standard size test piece, as follows:

Diameter of parallel length	0·357 in.
Cross-sectional area	0·100 sq.in.
Gauge length	1·26 in.
Parallel length	1·42 in. minimum
Radius at shoulder	0·31 in. minimum

Testing was to be carried out on an Avery Charpy testing machine of 30 kg.m capacity. Temperature control was to be obtained, above room temperature, in a thermostatically controlled water bath, and below room temperature, in a calorimeter containing ether cooled by solid carbon dioxide.



1—*Outlines of weld sections showing:* (a) *Location of Charpy* **V***-notch specimen and line of notch root;* (b) *location of drill hole for manganese determination sample;* (c) *area of hardness survey;* (d) *section for micro-fissure survey*

It was intended that the welds should be radiographically examined before machining, to locate imperfections which could then be avoided in the test pieces. The welds were to be examined metallographically, and hardness surveys were to be carried out.

The weld deposits were also to be analysed for carbon nitrogen, oxygen, and manganese. The manganese determination was suggested as a means of establishing the extent of weld dilution by the parent plate, in view of the high manganese content of the plate.

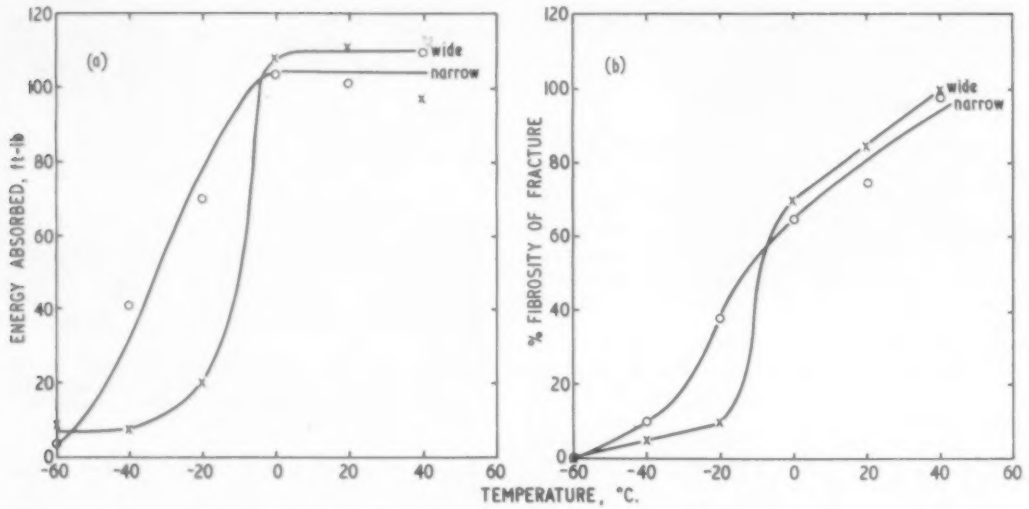
A survey was to be made to determine any relationship between the notch ductility of the welds and their micro-fissuring.

The plate material was to be selected by examination for freedom from laminations. The analysis of the plate is included in Table IX. Fracture transition data were obtained for the parent plate, for comparison purposes.

Table I

Transition temperatures of weld metal

Weld	*Transition Temperature, °C., on Basis of Criteria:*					
	15 ft.lb Level		*Mid-Point of Curve*		*50% Fibrous Fracture*	
	A	*B*	*A*	*B*	*A*	*B*
R16D	−40	−20	−14	+15	−12	−2
R26D	−34	−14	+7	+5	−10	+8
C36D	−45	−36	−18	−10	−26	−14
C46D	−33	−22	−16	+5	−20	0
B56D	−33	−10	+16	+32	−4	+40
B66D	−20	−34	+22	+11	+20	+4
R16O	−5	0	+21	+11	0	+3
R26O	−1	+1	+25	+10	+6	+16
C36O	−32	−14	−15	+1	−23	+12
C46O	−43	−18	−1	+3	−8	−12
B56O	−12	−8	+39	+42	+40	+20
B66O	−7	−18	+29	+26	−6	+20
R16V	−14	−14	+19	+23	+5	+13
R26V	−37	−7	+13	+16	+5	+4
C36V	−16	−30	+6	+6	−5	−3
C46V	−6	−38	+27	−12	+22	−18
B56V	−4	−6	+34	+35	+10	+23
B66V	+3	−5	+19	+23	+14	+19
R16HV	−26	−22	−12	−4	−14	0
R26HV	−30	−6	−4	+8	−14	−9
C36HV	−40	−20	−19	+1	−18	−10
C46HV	−45	−50	−22	−33	−20	−9
B56HV	−14	−6	+25	+31	+21	+19
B66HV	−13	−9	+39	+27	+22	+11



2—*Preliminary tests—Charpy curves for wide and narrow plates, using criteria of* (a) *energy absorption, and* (b) *fracture appearance*

It was agreed that, in view of the possible effect of rate of cooling on the properties of the welds, there should be some preliminary tests on welds made between plates of different widths.

The sets of plates were 18 in. long by 2 in. and 6 in. wide. Charpy **V**-notch and tensile test pieces were cut from the welds and used to establish any differences resulting from variations in cooling rates between the two welds.

Preliminary Tests

Contractor *C* prepared two sets of welds, one made between pairs of plates 2 in. wide, and the other between pairs of plates 6 in. wide. Charpy test pieces and tensile test pieces were machined from the welds as outlined above. The former were impact-tested over a range of temperature; absorbed-energy/temperature curves and fibrous-area/temperature curves were constructed, and are given in Fig. 2.

The tensile test results were as follows:

	Yield Stress tons/sq.in.	*U.T.S., tons/sq.in.*	*Elongation, %*
Narrow plate	27·5	33·5	33·3
Wide plate	30	34·8	27

At this stage it was decided to standardize the effect of cooling rate by making the main test welds 32 in. long between plates 6 ft wide, cutting each weld out and rejoining the plates with the next weld. This procedure continued as long as the plates were not less than 3 ft wide each.

Experimental Procedure and Results

Test welds were prepared by contractors *A* and *B*, and were designated according to the following code:

(i) A letter to identify the type of electrode, *i.e.*, *R*, rutile; *C*, cellulosic; *B*, basic

(ii) A number to identify the brand, which had the classification numbers: 1, E.316; 2, E.319; 3, E.110P; 4, E.110 5, E.619; 6, E.614

(iii) A number to identify the gauge of electrode, in s.w.g.

(iv) A letter to identify the position of welding, *i.e.*, *D*, downhand; *V*, vertical, *O*, overhead; *HV*, horizontal-vertical

(v) The letters '*A*' and '*B*' indicate welds prepared by contractors *A* and *B* respectively.

All welds were in fact made with 6 s.w.g. electrodes.

Main impact investigations

The welds were machined according to the programme, and the Charpy test pieces were used to determine the impact/temperature characteristics over the range —60°C. to 80°C. The temperature limits for individual welds were those necessary to produce a fracture appearance range from 0% to 100% fibrous.

The results have been plotted in detail in an earlier report*. The individual curves are also compared according to welding position in Figs. 3 and 4, and particular electrodes are compared for different positions in Figs. 5 and 6.

From these curves, transition temperatures based on the following criteria were obtained:

(i) 50% fibrous fracture

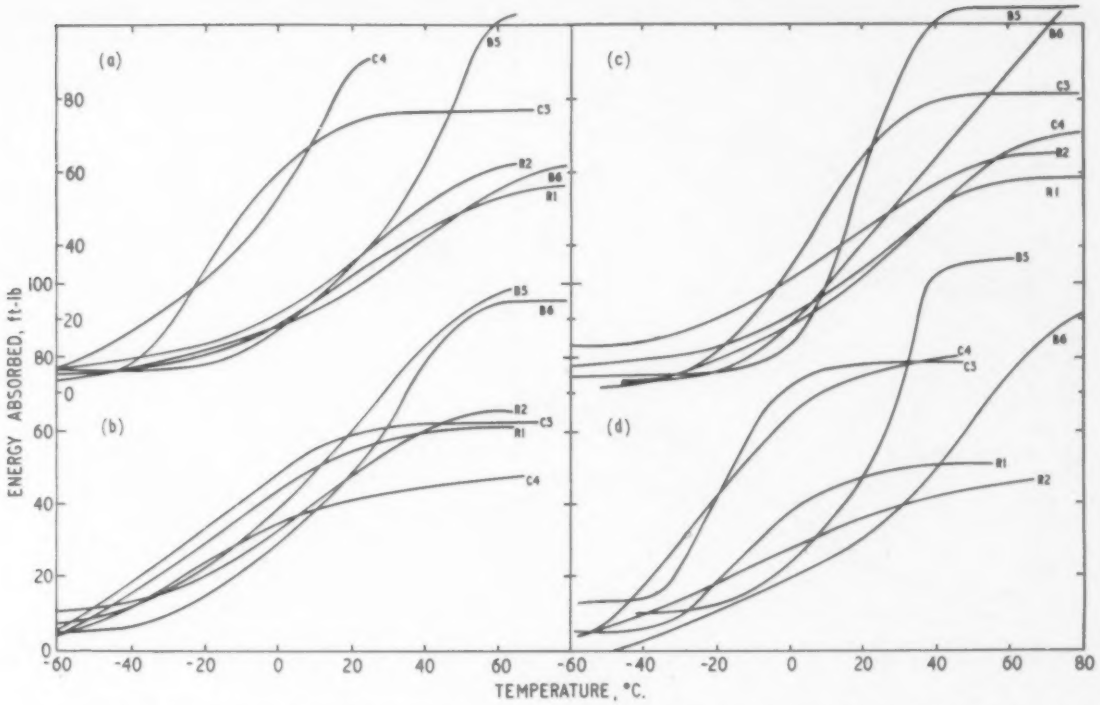
(ii) Fracture absorbing 15 ft.lb energy

(iii) Fracture absorbing energy equal to the mean of the maximum and minimum fracture energy.

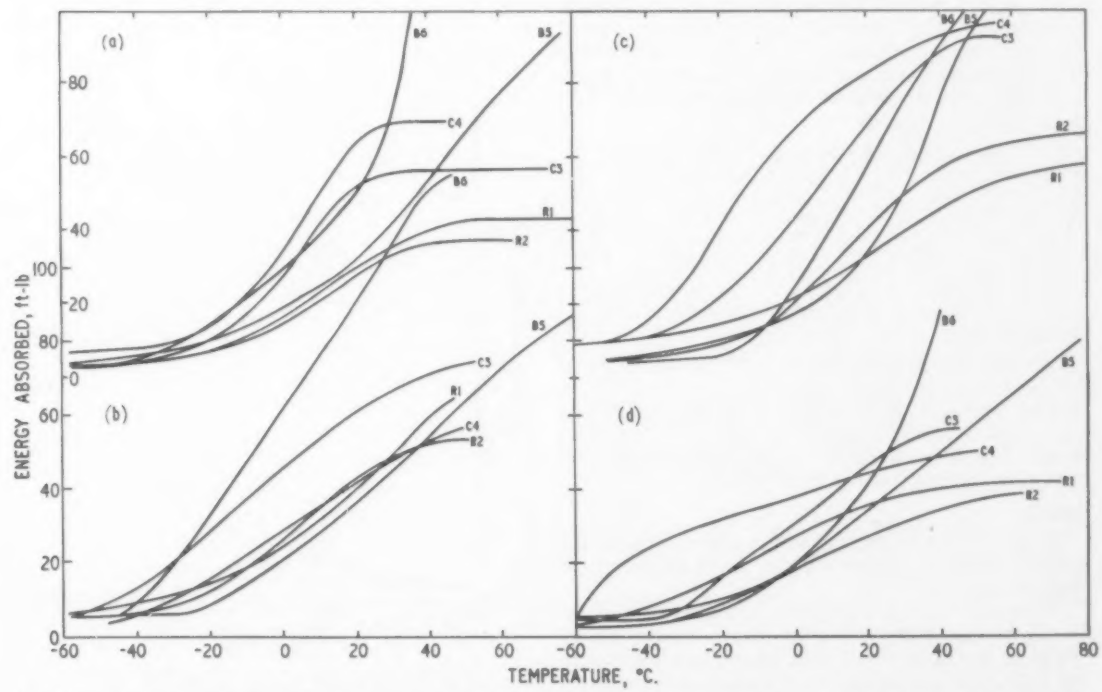
These transition temperatures are listed in Table I and illustrated in Fig. 7.

The testing temperatures were obtained as outlined in the programme, except that, for low temperatures, acetone cooled by solid carbon dioxide was used in place of ether, so that any water present should not precipitate as ice; this precipitation occurs with ether, and causes the test pieces to freeze together.

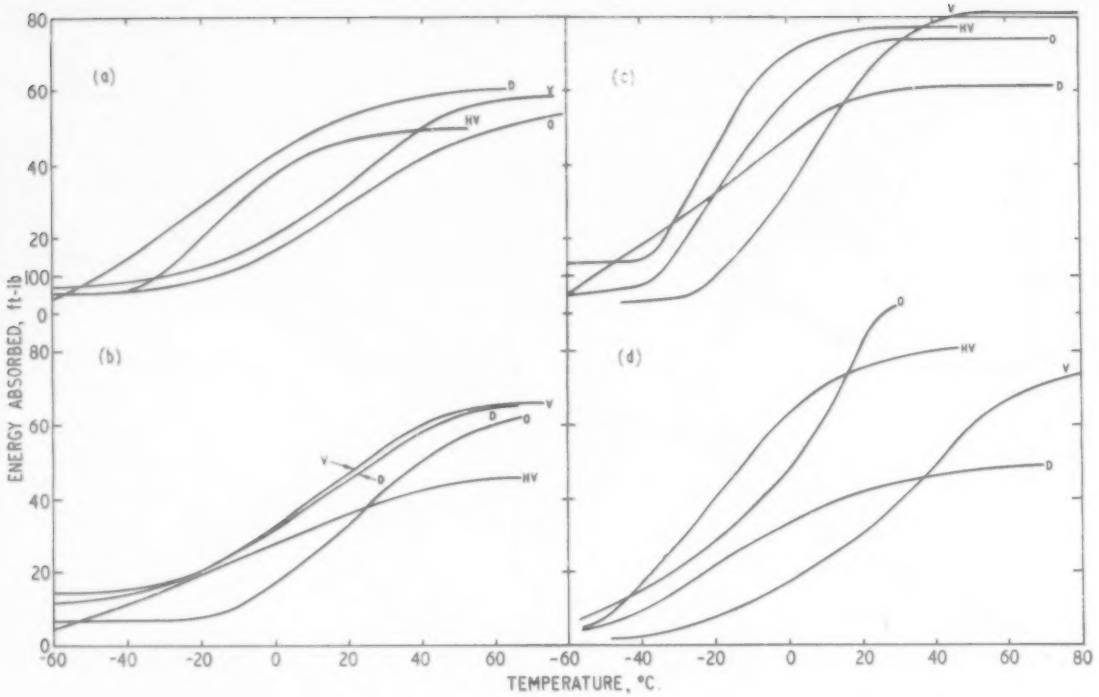
*B.W.R.A. Committee report FE.19/66A.



3—*Comparisons of impact curves for welds made with different electrodes in same welding position, weld series* A: (a) *Overhead;* (b) *downhand;* (c) *vertical;* (d) *horizontal-vertical*



4—*Comparisons of impact curves for welds made with different electrodes in same welding position, weld series* B: (a) *overhead;* (b) *downhand;* (c) *vertical;* (d) *horizontal-vertical*



Specimens were transferred from the temperature-controlled baths to the anvil of the testing machine, with metal forceps which were temperature-adjusted in the same baths. The total interval, from the time of the specimen leaving the surface of the bath to actual fracture in the machine, was never more than 3 sec. The maximum temperature error involved in this was as follows:

Room Temp., °C.	*Testing Temp.*, °C.	*Max. Error*, °C.
+20	−60	8
+20	−40	3
+20	−20	1·5
+20	0	1·0
+20	+40	1·0
+20	+60	1·5
+20	+80	3

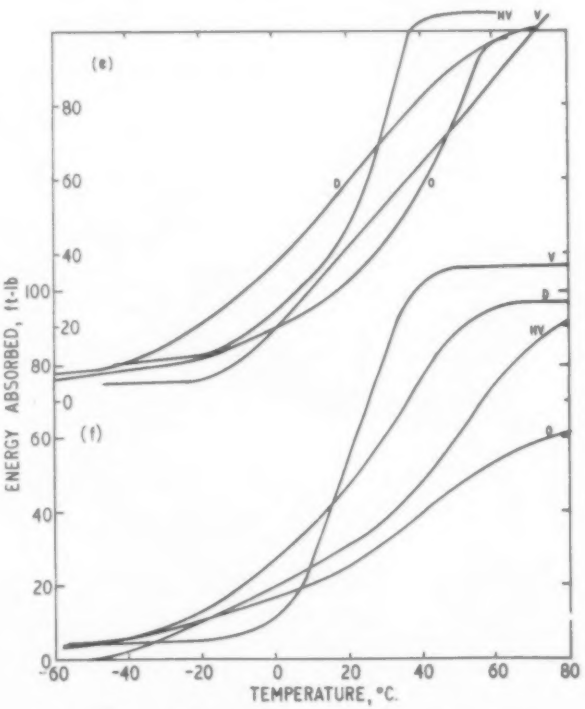
Tensile testing

The test pieces machined from the welds prepared by both contractors *A* and *B* were broken in an Amsler hydraulic tensile testing machine, thus making autographic records available for reference. The usual tensile data thus obtained, and also check hardnesses on the test pieces, are listed in Table II.

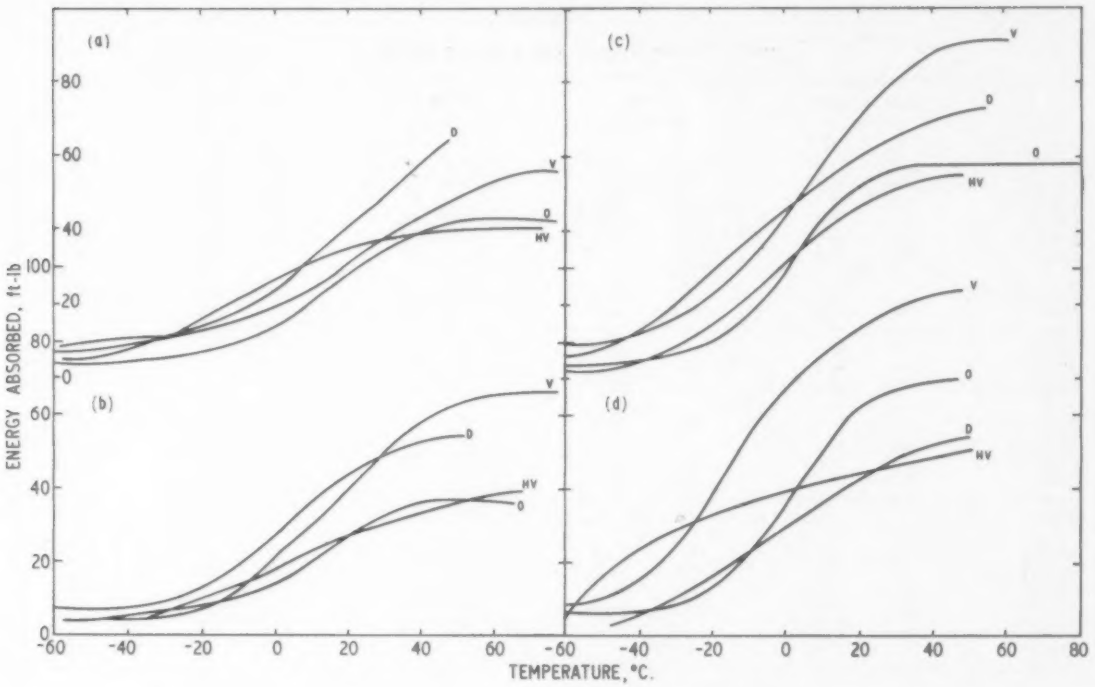
Analysis

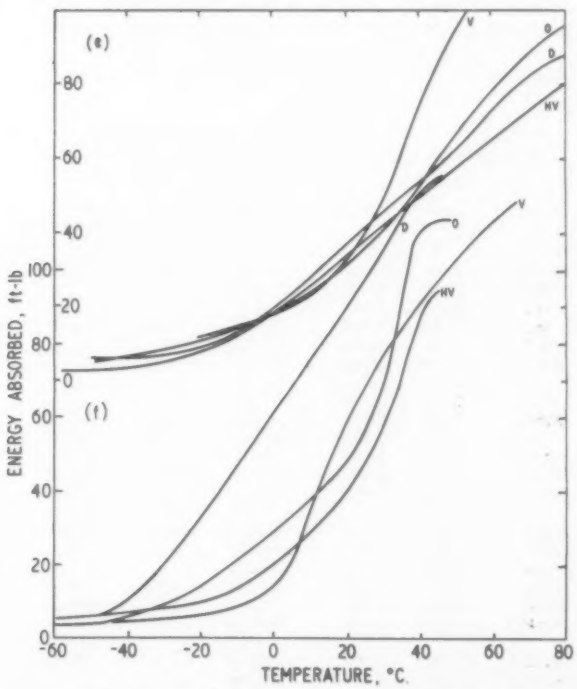
A check analysis, on the plate material supplied for the tests, basically agreed with that given by contractor *A* (*see* Table IX).

In view of the high manganese content of the plate, it was decided to check that no dilution of the weld by the plate had occurred. A drill sample was taken from the weld, from a position corresponding to a machined Charpy piece (*see* Fig. 1*b*), and a manganese determination was made; this value was then compared with

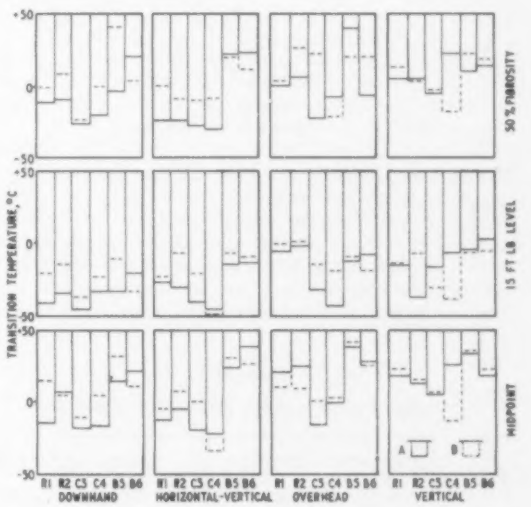


5—*Comparisons of impact curves for welds made in different welding positions with same electrode, weld series* A. *Electrodes:* (a) *rutile*, R1; (b) *rutile*, R2; (c) *cellulosic*, C3; (d) *cellulosic*, C4; (e) *basic*, B5; (f) *basic*, B6





6—*Comparisons of impact curves for welds made in different welding positions with same electrode, weld series* B. *Electrodes:* (a) *rutile*, R1; (b) *rutile*, R2; (c) *cellulosic*, C3; (d) *cellulosic*, C4; (e) *basic*, B5; (f) *basic*, B6



7—*Transition temperatures of weld metal, grouped according to welding position and transition criterion*

typical maganese contents of welds made with the electrode concerned. Full comparisons are given in Table III for welds made by contractor *A*. As the deviations in manganese contents were mainly small, a shorter series of determinations was made on the welds made by contractor *B*, using in each of three electrode covering groups welds which had previously shown the maximum deviation from typical and also those which had shown the minimum deviation. These results are included in Table III.

Table II

Results of tensile tests in Amsler machine

Weld	*Yield Strength, tons/sq.in.*		*U.T.S., tons/sq.in.*		*Elong., %*		*Red. in Area, %*		*Hardness D.P.N.*	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
R16D	32·0	35·9	37·5	33·9	25	18	50	32	198	201
R26D	35·0	36·1	39·5	38·5	14	14	30	18	205	185
C36D	—	32·7	30·0	35·4	5	12	10	23	183	202
C46D	—	35·4	32·0	37·5	5	12	8	27	181	192
B56D	38·0	36·6	41·5	39·6	—	26	20	50	194	191
B66D	38·0	34·5	42·5	38·7	21	32	35	68	210	205
R16O	32·0	32·7	38·4	36·5	17	15	33	15	198	211
R26O	35·0	32·8	41·0	36·1	17	12	30	25	187	186
C36O	32·0	33·5	37·0	36·3	15	8	25	10	177	192
C46O	*	36·4	*	39·6	*	12	*	20	*	202
B56O	36·0	39·7	42·0	44·0	23	23	40	50	188	195
B66O	30·0	36·1	31·0	40·2	7	27	10	60	190	215
R16V	29·0	32·6	36·0	38·9	25	26	45	55	182	182
R26V	32·0	31·7	37·5	37·3	25	14	40	25	170	191
C36V	25·5	27·3	33·5	34·5	36	24	65	35	188	193
C46V	25·0	31·3	33·5	35·7	13	20	20	40	160	167
B56V	37·0	—	38·5	34·3	8	5	15	10	187	198
B66V	—	—	30·0	36·0	—	14	—	20	189	192
R16HV	33·0	33·8	39·5	38·4	23	16	45	25	186	175
R26HV	33·0	35·4	40·0	37·4	14	8	15	15	250	189
C36HV	32·3	32·4	34·7	36·2	7	12	25	20	158	185
C46HV	32·8	35·3	33·8	38·4	10	12	25	28	174	196
B56HV	34·0	39·9	37·5	43·3	30	16	65	25	192	240
B66HV	36·3	36·8	39·7	40·9	27	28	60	66	209	212

* Impossible to machine test piece, owing to large voids.

Table III shows that, although some dilution of the weld by the plate material may occur, there was no noticeable change in manganese content in the region from which the test pieces were machined.

The weld deposits were also analysed for carbon, nitrogen, and oxygen (*see* Table IV). In the case of the nitrogen, determinations were made on all '*A*' welds; oxygen determinations were limited to 12 of the '*A*' welds. The nitrogen results are linked with the impact results in Figs. 8*a* and *b*. These show the connection between welding position and nitrogen content, and that the welds of lower nitrogen content have lower transition values. The oxygen results are plotted and grouped according to welding position in Fig. 9; it is seen that the oxygen content of the welds is more dependent on electrode covering than on welding

Table III

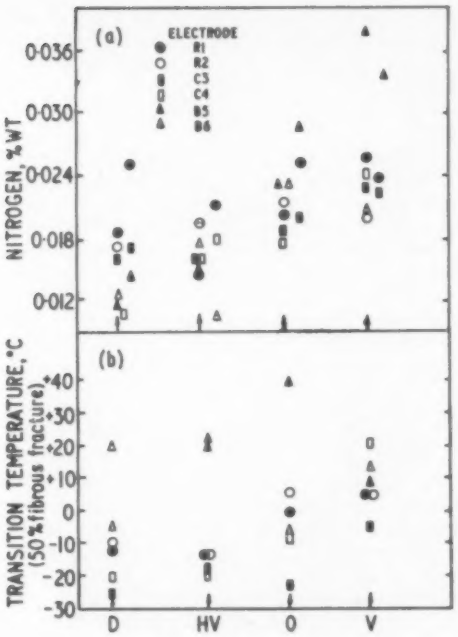
Manganese contents of test welds and of typical welds

Weld No.	*Manganese Content, %*		*Weld No.*	*Manganese Content, %*	
	Actual	*Typical*		*Actual*	*Typical*
R16D A	0·41	0 37	*R16V A*	0·37	0·37
R26D A	0·58	0·3–0·4	*R26V A*	0·53	0·3–0·4
C36D A	0·43	0·4–0·55	*C36V A*	0·51	0·4–0·55
C46D A	0·63	0·6	*C46V A*	0·59	0·6
B56D A	0·95	0·7–0·95	*B56V A*	0·66	0·7–0·95
B66D A	0·76	0·6	*B66V A*	0·57	0·6
R16O A	0·37	0·37	*R16HV A*	0·39	0·37
R26O A	0·52	0·3–0·4	*R26HV A*	0·56	0·3–0·4
C36O A	0·41	0·4–0·55	*C36HV A*	0·43	0·4–0·55
C46O A	0·72	0·6	*C46HV A*	0·7	0·6
B56O A	0·73	0·7–0·95	*B56HV A*	0·58	0·7–0·95
B66O A	0·57	0·6	*B66HV A*	0·72	0·6
R26D B	0·32	0·3–0·4	*C46O B*	0·69	0·6
R16O B	0·41	0·37	*B56O B*	0·92	0·7–0·95
C36HV B	0·60	0·4–0·55	*B66D B*	0·65	0·6

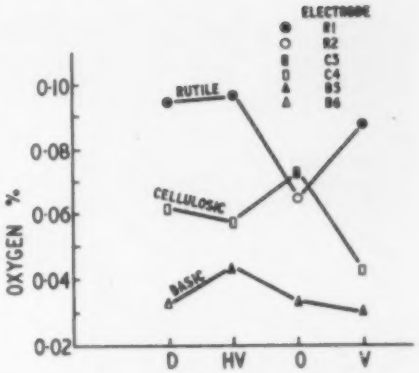
Table IV

Analyses of weld deposits for carbon, nitrogen and oxygen

Weld	*Carbon Content, %*		*Nitrogen Content, %*		*Oxygen, %*
	A	*B*	*A*	*A (repeat)*	*A*
R16D	0·083	0·100	0·0185	0·0254	0·0948
R26D	0·085	0·092	0·0165	—	—
C36D	0·090	0·095	0·0160	—	—
C46D	0·088	0·093	0·0110	0·0169	0·0621
B56D	0·087	0·096	0·0120	—	—
B66D	0·090	0·082	0·0125	0·0145	0·0332
R16O	0·094	0·100	0·0200	—	—
R26O	0·088	0·095	0·0215	0·0250	0·0653
C36O	0·900	0·093	0·0185	0·0196	0·0732
C46O	0·092	0·087	0·0175	—	—
B56O	0·088	0·095	0·0230	0·0285	0·0335
B66O	0·086	0·095	0·0230	—	—
R16V	0·110	0·092	0·0255	0·0235	0·0881
R26V	0·082	0·083	0·0200	—	—
C36V	0·098	0·090	0·0235	—	—
C46V	0·096	0·090	0·0240	0·0222	0·0433
B56V	0·094	0·088	0·0380	0·0337	0·0310
B66V	0·083	0·081	0·0210		—
R16HV	0·092	0·098	0·0150	0·0213	0·9650
R26HV	0·088	0·084	0·0190	—	—
C36HV	0·089	0·122	0·0160	—	—
C46HV	0·090	0·095	0·0160	0·0180	0·0580
B56HV	0·081	0·084	0·0155	0·0100	0·0442
B66HV	0·095	0·077	0·0180	—	—



8—(a) *Nitrogen contents, and* (b) *impact properties (transition temperatures for 50% fibrous fracture), for welds from contractor* A



9—*Oxygen contents of weld metal, of welds from contractor* A

position. Thus, the highest oxygen contents occur in welds made with rutile-covered electrodes, whilst basic-covered electrodes give welds with the lowest oxygen contents.

Hardness surveys

Hardness surveys were carried out on a macro scale, on transverse sections of the welds, using an adapted microscope stage traverse, clamped to the sliding table of the Vickers hardness testing machine.

In general, hardness measurements were made over an area of 10 × 10 mm, in rows and columns spaced at

Table V

Hardness surveys

Weld	*No. of Detns.*		*Min. Hardness, D.P.N.*		*Max. Hardness, D.P.N.*		*Range, D.P.N.*		*Average Hardness, D.P.N.*	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
R16D	36	36	176	175	197	207	25	32	184	187
R26D	36	34	170	180	199	207	29	27	187	188
C36D	36	36	153	161	203	199	50	38	173	193
C46D	36	34	169	187	206	219	37	32	180	201
B56D	36	36	198	194	236	221	38	27	218	207
B66D	36	36	198	183	242	212	44	29	215	197
R16O	35	36	170	177	201	221	31	44	186	199
R26O	36	35	170	181	197	227	27	46	184	197
C36O	35	35	160	187	225	224	65	37	182	203
C46O	33	34	156	181	191	238	35	57	171	182
B56O	36	35	207	201	254	238	47	37	229	222
B66O	*	36	*	175	*	227	*	52	*	188
R16V	36	36	161	167	196	221	35	54	180	181
R26V	36	36	167	161	201	198	34	37	180	176
C36V	36	36	162	167	206	188	44	21	184	176
C46V	35	36	161	160	185	185	24	25	171	168
B56V	32	36	185	181	242	224	57	43	209	196
B66V	35	36	164	175	194	203	30	28	177	177
R16HV	35	36	175	181	199	211	24	30	186	197
R26HV	35	35	185	191	219	221	25	30	196	202
C36HV	36	32	169	178	197	225	28	47	179	194
C46HV	35	34	167	182	201	218	34	36	184	197
B56HV	36	35	172	194	235	233	63	39	195	197
B66HV	36	36	207	177	249	219	42	42	228	199

* No survey made, owing to extensive macro-porosity.

2 mm intervals. The square-based diamond pyramid indenter was used throughout, loaded with 10 kg.

This area of survey was chosen to coincide with the section from which the Charpy test piece was machined (*see* Fig. 1*c*), on the centre-line of the weld and approximately 2 mm below a line produced from the surface of the parent plate.

The results obtained are given in abbreviated form in Table V, which lists the actual number of determinations, the minimum and the maximum hardness recorded, the range of hardnesses, and the average values of determinations made.

From the results there appears to be no great variation of hardness over the section of the weld from which the Charpy test pieces were machined. There is also little difference between the results on welds made by the two contractors.

Macroscopic examinations

All the '*A*' welds were sectioned, polished, and etched, to show the macrostructures, and these were photographed for record purposes. A typical outline section is shown in Fig. 1*a*, with an indication of the position of the Charpy test piece, and its notch, relative to the section of the weld.

Welding sequence diagrams had been supplied with the '*B*' welds, and these were compared with the corresponding '*A*' weld macrostructures. The welding procedure appeared to be similar in most cases, the only variations being in the number of runs made to cover the width of the weld. For example, in welds *C36DB* and *C46DB* only two runs were made to cover the width of the weld, while in their '*A*' counterparts three runs had been used. A random selection of the '*B*' welds were sectioned and macro-etched. The structures revealed were in all cases in agreement with the welding sequence diagrams.

Radiography

Radiographs of the welds in the preliminary tests showed that the welds were sound in the area from which the test pieces were machined, although there were sparse inclusions at the edges of the welds.

No radiographs were made of the welds prepared by contractor *A*, and no account was taken of possible defects in the positioning of the notch of the Charpy test pieces. After the tests were completed, both the broken and unbroken test pieces were radiographed. In the former, it was difficult to establish the presence of any defects in the area of the notch; with the unbroken pieces defects in the notch were easily identified.

The welds made by contractor *B* were radiographed before machining, and assessments of these were made, both in detail and also of the machinability of the weld, *i.e.*, whether or not it could be machined to give a sufficient number of test pieces with sound metal in the critical testing zone. The results of the radiographic examination are given in Table VI, the suitability for machining being designated as follows:

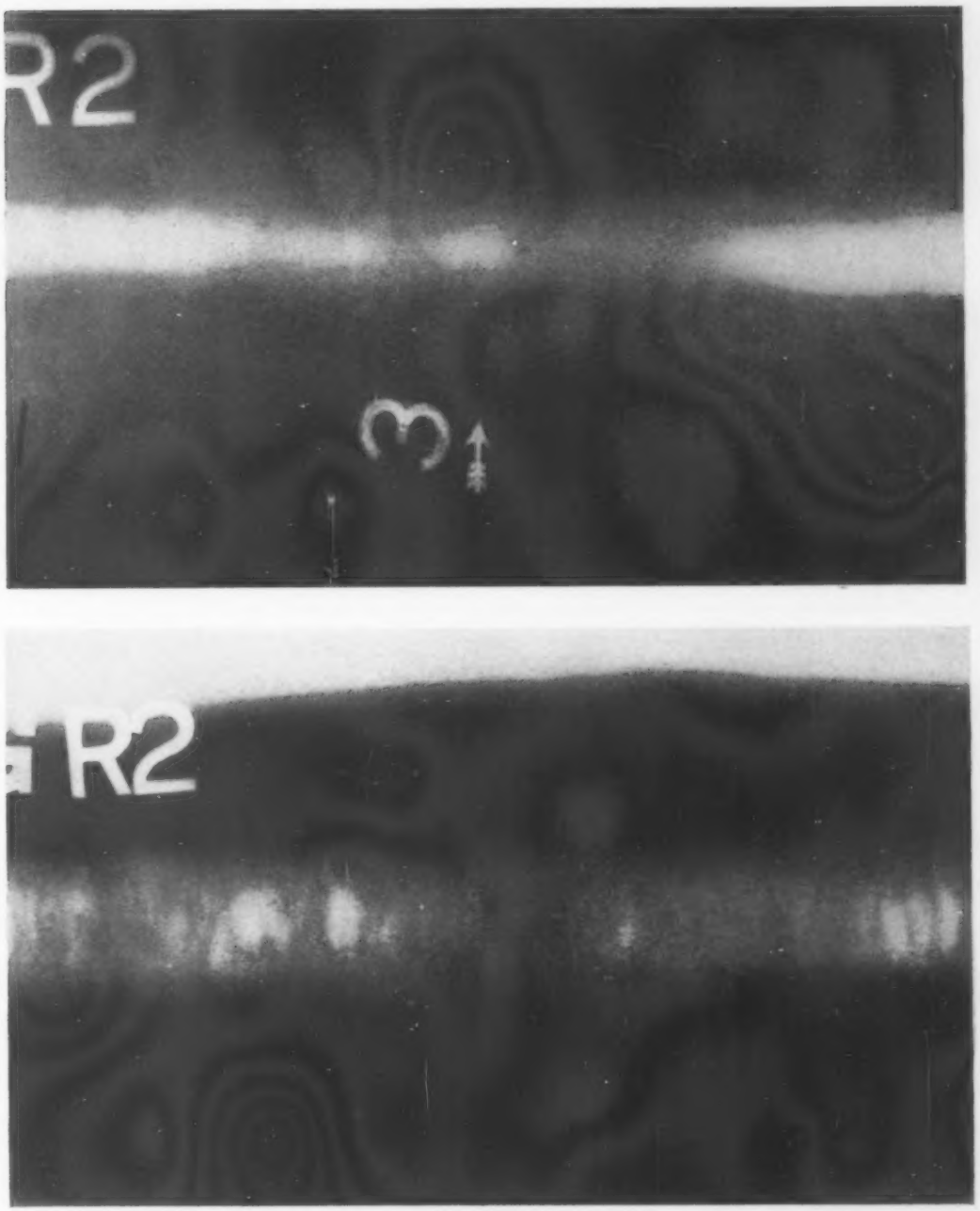
Sound—Test pieces could be machined without reference to position along the weld.
Avoidable—Defects could be avoided by specifying the position along the weld.
Not avoidable—Defects could not be so avoided. In this group, some sound test pieces could be selected, but not sufficient in number to carry out the full range of temperature tests. Accordingly, test pieces were machined in unsound

Table VI

Radiographic examination on test welds made by contractor *B*

Weld	*Porosity in parts of weld*			*Comments*
	Length 1–2	*Length 2–3*	*Length 3–4*	*(Suitability for machining)*
R16D	Aligned 6 in.	Aligned, 3 in.	Aligned	Avoidable
R26D	Nil	Nil	Nil	Sound
C36D	Scattered,fine	Scattered, fine	V. slight	Not avoidable
C46D	,, ,,	,, ,,	Scattered, fine	Not avoidable
B56D	Nil	At 2 starts	At 2 starts	Sound
B66D	Nil	Nil	Nil	Sound
R16O	Spot porosity	Aligned fine. Spot med.*	Aligned, fine. Spot med.*	Avoidable
R26O	Scattered and aligned, fine*	Scattered, fine	Scattered, fine	Avoidable
C36O	Scattered, fine	Med.	Scattered, fine and med.*	Not avoidable
C46O	Dense, fine and med.*	Dense, fine and med.*	Scattered; dense, fine and med	Avoidable
B56O	Spot	Scattered, fine	Scattered, fine	Avoidable
B66O	Scattered, fine	,, ,,	,, ,,	Avoidable
R16V	Nil	Nil	Nil	Sound
R26V	Scattered, fine	Scattered, fine	Scattered, fine	Avoidable
C36V	,, ,,	Aligned, ,,	Aligned, fine	Avoidable
C46V	Scattered and aligned, fine and med.*	Scattered, fine and med.*	Scattered, fine and med.*	Not avoidable
B56V	Scattered, med.	Scattered, med.	Scattered, med.	Not avoidable
B66V	,, med. and gross*	,, med. and gross*	,, med. and gross*	Doubtful
R16HV	Nil	Nil	Nil	Sound
R26HV	Scattered, fine	Scattered, fine	Scattered, fine	Not avoidable
C36HV	,, med.	,, med.	,, med.	Doubtful
C46HV	,, fine	,, fine	,, fine	Not avoidable
B56HV	Nil	Nil	Nil	Sound
B66HV	1 in. fine	2 in. fine	Nil	Avoidable

* These lengths contain more than one type of porosity.



(a)

(b)

10—*Radiographs of specimen welds, showing degrees of porosity* (see *Table VI*): (a) *sound;* (b) *avoidable*

metal, taking advantage also of the sound areas which did exist.

Doubtful—Welds in which sound metal was very rare and the general quality of which would be unlikely to be accepted under any radiographic standard specification.

Radiographs corresponding to these degrees of soundness are shown in Fig. 10.

Table VII sets out the results of the radiography on broken and unbroken test pieces machined from the welds made by contractor *A*.

Micro-fissure survey

It was decided, after consideration, to make the micro-fissure counts on the longitudinal section of the welds, normal to the plane of the parent plate. Sections

(c)

(d)

10—*Radiographs of specimen welds, showing degrees of porosity (see Table VI):* (c) *not avoidable;* (d) *doubtful*

were prepared by wet-grinding to 600 mesh, and then electro-polishing for 5 min at 2 amp in a bath containing 5% chromic acid, 15% sulphuric acid, 65% phosphoric acid, and 15% water. This procedure etched the fissures to show clearly on a bright steel background. The fissures were counted under a low-power binocular microscope, the results being expressed as fissures per square inch of section. The survey was limited to twelve welds, one of each covering type in each welding position.

The results, which are given in Table VIII and summarized in Fig. 11, show that in all welding positions the cellulosic-covered electrodes have produced the greatest number of fissures per unit area. In the

Table VII

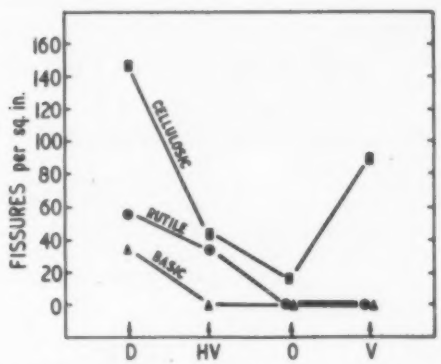
Radiographic examination on Charpy weld metal test pieces from '*A*' welds

Weld	*Porosity in parts of test piece*			*Comments*
	Length 1–2	*Length 2–3*	*Length 3–4*	*(Suitability for machining)*
R16D	Nil	Nil	Scattered, v. fine	Sound
R26D	Nil	Nil	,, ,,	Sound
C36D	Nil	Nil	,, ,,	Sound
C46D	Nil	Aligned, fine	,, fine	Avoidable
B56D	Nil	Nil	Nil	Sound
B66D	Scattered, fine	Nil	Nil	Avoidable
R16O	Aligned, fine	Scattered, fine	Scattered, fine	Avoidable
R26O	Scattered, fine	,, ,,	,, fine	Avoidable
C36O	,, gross	,, med.	,, gross	Doubtful
C46O	,, gross	,, med.	,, med.	Doubtful
B56O	,, fine and med.	,, fine and med.	,, fine	Avoidable
B66O	,, and aligned, gross	,, and aligned, gross	,, and aligned, gross	Doubtful
R16V	Nil	Scattered, fine	Scattered, fine	Avoidable
R26V	Scattered, fine	,, and aligned fine	,, and aligned, fine	Avoidable
C36V	,, fine	,, fine	Nil	Avoidable
C46V	,, fine and med.	,, fine	Scattered, fine	Avoidable
B56V	,, med. and gross	,, med. and gross	,, med. and gross	Doubtful
B66V	,, med.	,, med.	,, fine	Not avoidable
R16HV	Spot	Nil	Scattered, v. fine	Avoidable
R26HV	Scattered, fine	Scattered, fine	,, fine	Avoidable
C36HV	,, fine and med.	,, fine	,, fine	Not avoidable
C46HV	,, fine and gross	,, fine	,, fine	Avoidable
B56HV	,, fine	,, fine and med.	,, fine	Avoidable
B66HV	,, fine	,, fine	,, fine	Avoidable

overhead and vertical welding positions both the rutile and basic electrodes produced no fissures in the sections examined. In the downhand and horizontal-vertical positions, the basic electrodes gave fewer fissures than the rutile. The downhand position provided the greatest concentration of fissures for all three electrode types.

Plate investigation

Sufficient plate material was obtained from the contractors to machine 12 Charpy test pieces and one tensile test piece. These were then tested under the same conditions as the test pieces from the welds to obtain equivalent impact and tensile data, and these are given in Table IX. This also includes the results of the plate analysis provided by contractor *A*, and the check analysis carried out by the author.



11—*Micro-fissure counts on welds from contractor* A

Summary of Results

The transition characteristics of the basic electrodes, on the basis of all three criteria (50% fibrous fracture, fracture absorbing 15 ft.lb energy, and mean fracture energy), are poorer than those of the rutile and cellulosic types, in all welding positions. The cellulosic types is, in turn, better than the rutile in all welding positions, excepting only the vertical welds from contractor *A*.

The difference between the brands of any one type, in any one position, is in most cases quite small.

Generally speaking, the downhand welding position produces welds with the lowest transition temperatures increasing through horizontal-vertical and overhead to vertical welds, which have the highest transition temperatures. Not all electrodes, however, follow this pattern. For example the basic electrodes give lowest values in the downhand position, but this is followed in increasing order by the vertical, overhead, and horizontal-vertical positions.

The micro-fissure survey confirms that the basic type electrode is better able to produce a fissure-free deposit than either the rutile or cellulosic types.

Table VIII

Results of micro-fissure survey

Weld	*Fissures/sq.in.*	*Weld*	*Fissures/sq.in.*
R16D	56·3	*R16V*	0
C36D	147	*C36V*	90·9
B56D	34·5	*B56V*	0
R16O	0	*R16HV*	32·7
C36O	16·3	*C36HV*	43·6
B56O	0	*B56HV*	0

Table IX

Composition and properties of parent plate

Composition

Analysis by	*Composition, %*				
	C	*Mn*	*S*	*P*	*Si*
Contractor *A*	0·14	1·18	0·042	0·025	0·03
B.W.R.A.	0·11	1·14	0·041	0·031	0·05

Tensile Properties (Hounsfield Tensometer, Test piece 0·252 in. dia.)

	Test Piece		*Average*
	1	*2*	
Yield stress, tons/sq.in.	15·4	15·2	15·3
U.T.S., tons/sq.in.	27·9	28·0	27·95
Elongation, %	50	48	49
Red. in area, %	70	69	69·5

Impact Properties (Charpy V-notch specimen, longitudinal direction)

	Series N		*Series P*	
Testing Temp.,	*Energy Absorption, ft. lb.*	*% Fibrous*	*Energy Absorption, ft. lb.*	*% Fibrous*
+40	96·5	95	98	95
+30	78	75	149	100
+21	82·5	70	104·5	92·5
0	78	60	74	40
−10	37	10	26·5	7·5
−20	15	2	11	2
−30	7	0	12	0
−40	6·5	0	7·5	0

Series N—Notch normal to natural plate surface
Series P—Notch parallel with plate surface

Discussion of Results

The work described has fulfilled the main object of the programme: to assess any inherent differences in the notch ductility of welds made with basic, rutile, and cellulose electrodes, with particular reference to lower temperatures. The cellulose electrodes have shown the best Charpy V-notch impact properties in all welding positions employed, followed by the rutile and basic types. This confirms indications from the work of other investigators.*†

Care should, however, be taken in the application of these results to the problem of brittle fracture in large platework structures. The Charpy V-notch test is only one measure of the properties required of weld deposits suitable for these structures, and other important considerations apply. Thus, although basic electrodes have shown generally poorer impact results in this work, they nevertheless offer certain well-established advantages, notably weld metal with marked freedom from micro-fissuring, and a high resistance to cracking under severe conditions of cooling and restraint. The former point is upheld in these investigations. In these respects basic electrodes are more suited than cellulose electrodes, for application to large platework structures.

Further work would, of course, be necessary to establish the reasons for the relatively high transition temperature of weld metal deposited by basic electrodes, and to show whether such electrodes could be improved in this respect.

Acknowledgments

The author wishes to acknowledge the assistance of the Motherwell Bridge and Engineering Co. Ltd., Whessoe Ltd., and Murex Welding Processes Ltd., in preparing the test welds. Thanks are due to Mr. L. W. Derry, Mr. V. Dickin, and Mr. H. G. Vaughan for their advice and assistance, also to Mr. R. M. Brown for his assistance in interpretation and assessment of the radiographs. Thanks are also due for assistance in obtaining the nitrogen and oxygen analyses which were carried out in the research laboratories of The United Steel Companies, and elsewhere.

* W. S. PELLINI and E. W. ESCHBACHER: *Welding J.*, 1954, vol. 33, pp. 16s–20s.
† W. S. PELLINI: *Ibid.*, 1956, vol. 35, pp. 217s–233s.

B.W.R.A. REPORT

Mechanical Properties of Metal-Arc Welds in Galvanized Mild Steel

By

P. W. Jones, B.SC., A.I.M.

The effect on weldability and properties, of welding on galvanized plate and sheet was investigated by tensile, bend, hardness and impact tests. Mechanical properties were not affected appreciably. The galvanizing appeared to make hot cracking slightly worse, to reduce the severity of fissuring, and to have no effect on the microstructure. These results may inspire greater confidence in welds made on galvanized sheet.

THE object of the work was to evaluate the effect of a hot-dipped galvanized coating (applied before welding) on the properties and weldability of metal-arc welds in mild steel.

Tests were carried out to give a direct comparison between welds made under identical conditions on samples of the same steel, with and without a galvanized coating.

Types of Weld Used

Mild steel was used throughout, and welds were made only on surfaces that were free from scale, whether galvanized or not. The types of weld were:

(*a*) Butt welds in $\frac{1}{2}$ in. thick steel, machined with a 60° V preparation, with a $\frac{1}{16}$ in. root face, and welded with a $\frac{1}{16}$ in. root gap. Galvanizing was carried out after machining, so that the surfaces to be joined were heavily coated with zinc. These welds were used for all-weld-metal tensile test specimens, Charpy (V-notch) impact test pieces, and also for metallographic examination

(*b*) Square close-butt welds in $\frac{1}{8}$ in. sheet. The edges were prepared by shearing, so that zinc was not present on the faying surfaces. The welds were used for transverse tensile tests, for transverse and longitudinal bend tests, and for hardness tests

(*c*) Murex hot-cracking test welds. The test pieces were $3 \times 2 \times \frac{1}{2}$ in., galvanized after machining

(*d*) Bead welds on 1 in. plate, for fissure counts.

Measurements of Coating Thickness

The thickness of zinc on three of the steel plates used was measured microscopically. Sections were taken at right-angles to the plate surface and a protective layer of silver was electrodeposited before mounting. The results obtained were:

Plate	*Coating Thickness*
$\frac{1}{8}$ in.	0·004 in.
$\frac{1}{2}$ in. (hot-cracking test specimen)	0·002 in.
1 in.	0·006 in.

These were measurements on a single specimen only, but they give an indication of the coating thickness sufficient for the purposes of the investigation.

Macro- and Micro-Examination of the Welds

Examination for inclusions

Specimens of $\frac{1}{2}$ in. butt welds in plain and galvanized steel were examined for differences in microstructure and for traces of zinc-containing inclusions, such as zinc oxide. Although modern diamond polishing techniques of a high standard were employed, no differences between the two welds could be detected, and no inclusions peculiar to the galvanized steel were observed.

Shape of the weld beads

By taking transverse sections of beads deposited on 1 in. plate, it was observed that the beads made on galvanized steel had a more humped appearance than those on plain steel (Fig. 1). It is likely that this effect is associated with the greater difficulty of welding on a galvanized surface, which was reported by the welder.

Zinc Content of Welds

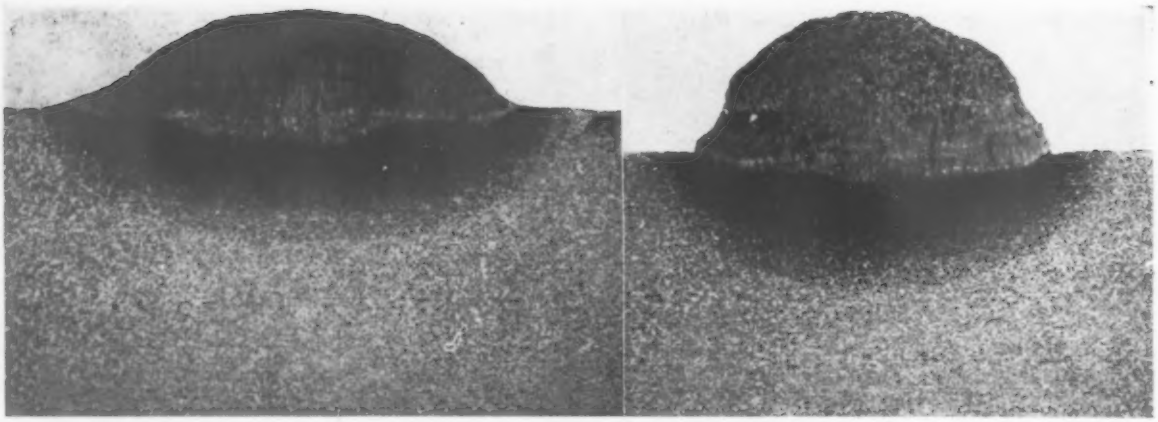
A few determinations of zinc content were made on some of the larger welds. The results, given in Table I, show that an appreciable amount of zinc was present in the welds made on galvanized steel.

Hot-Cracking Tests

Murex hot-cracking tests were carried out under standard conditions, as described by Jones,[1] using both galvanized and plain test pieces of the same steel.

Report ML/28 of the British Welding Research Association.

Mr. Jones, formerly a Senior Research Officer with the Association, is now at Marshall's Flying School, Cambridge.



(a) (b)

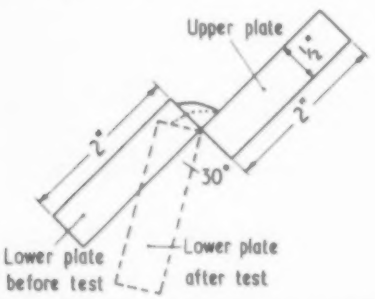
1—*Comparison of bead shapes made with 12 s.w.g. electrode* E, *1½ in. per in. weld:* (a) *Plain mild steel;* (b) *galvanized steel*

Table I

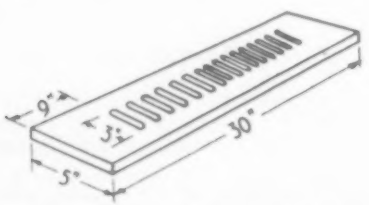
Zinc contents of welds

Electrode B.S.1719 Class	*Code*	*Steel Condition*	*Type of Weld*	*Zinc Content, %*
E 319	E	Galvanized	Murex Test*	0·08
E 616	AO	Galvanized	Murex Test	0·10
E 616	AO	Galvanized	Murex Test	0·16
E 319	E	Plain	Murex Test	Trace
E 616	AO	Plain	Murex Test	Trace
E 219	B	Galvanized	¼ in. Butt†	0·05
E 616	AO	Galvanized	⅜ in. Butt‡	0·04

* Hot-cracking test (fillet weld)
† Sample taken from broken all-weld-metal tensile specimen (Weld No. 178, Table IV)
‡ Sample taken from broken all-weld-metal tensile specimen (Weld No. 173, Table IV)



2—*Murex hot-crack test specimen, showing positions at start and end of test*



3—*Position of weld beads on test plate for fissures*

In the Murex test, a fillet weld is laid between two plates which are rotated so as to open out the weld during its deposition, as shown in Fig. 2. The severity of cracking is assessed by measuring the distance between the start of the weld and the furthermost extent of the crack. A full-length crack, ignoring the weld crater, is 2·5 in. long.

The results of crack length measurements, given in Table II, show that some deterioration in hot-cracking properties appears to be associated with galvanizing. The specimens had a heavy accumulation of zinc at the site of the weld and this made the welding particularly difficult. It appears likely that a normal thickness of galvanizing will make very little difference, although a slight deterioration may be possible in welds subjected to exceptionally heavy restraint.

Fissure Counts

Fissures (also known as microcracks) are believed to be associated with the presence of hydrogen in weld metal and are not normally found in welds made with basic-covered 'low hydrogen' electrodes. These defects

Table II

Comparison of lengths of hot cracks for galvanized and plain steel

(Murex Hot-cracking Tests)

Electrode B.S.1719 Class	*Code*	*Crack Lengths, in. Galvanized*		*Plain*	
E 319	E	(*a*) 1·55, 1·5, 1·5, 1·9	1·6	(*d*) 2·0, 1·4	1·7
E 614	N	0·7		Nil	
E 616	AO	(*b*) 0·4, 0·25, 0·45	0·4	Nil	
E 616	AO	(*c*) 1·0, 0·7	0·9	(*e*) Nil	

Zinc Contents: (*a*) 0·8%; (*b*) 0·10%; (*c*) 0·16%; (*d*) trace; (*e*) trace.

are mostly found in rapidly-cooled welds, such as those made on thick plates without preheat. According to Flanigan and Kaufmann,[2] they are detrimental to fatigue, impact, and tensile properties. Despite this, it is understood that their effect has not prevented welds containing fissures from giving satisfactory service.

The effect of galvanizing on the incidence of fissuring was investigated by cutting two 30 in. lengths from a 5 in. × 1 in. mild steel bar. After removing the mill scale, one of the lengths was galvanized and the other retained in the plain condition for comparison.

Weld beads were then deposited on both plates, as shown in Fig. 3, using *E* electrodes (*E* 319 of the B.S.1719 Classification). The procedure was to cut an electrode in two, and to use one half for each plate. To ensure that the plates were always at room temperature at the commencement of each deposit, there was an interval of at least 4 hours between each weld.

When all the welds had been deposited, sections were cut from the middle of the weld length. The top of each weld was then machined, parallel with the plate surface, to half the depth of the fused material including that below the plate surface. These sections at half bead depth were then prepared for micro-examination. To make the fissures easily visible, the specimens were electrolytically polished, using the solution recommended by Imboden and Sibley.[3]

The results of these fissure counts are given in Table III and the relationship between the number of fissures and the energy input is shown in Fig. 4. Since the same plate thickness was used throughout, the energy input was inversely related to the cooling rate of the weld.

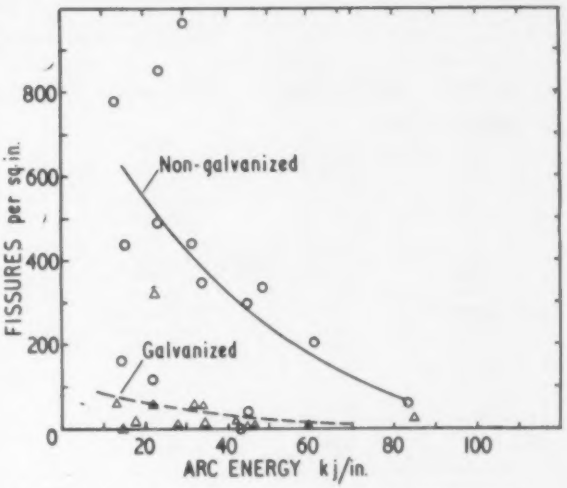
Although there is a considerable variation in the number of fissures for a given energy input, the reduction brought about by galvanizing is sufficiently great to be beyond doubt. The graph suggests that, under certain practical welding conditions, galvanized plate shows greater promise than plain plate of giving freedom from fissures.

A possible reason for the improvement brought about by galvanizing is the presence of a large quantity of zinc vapour in the arc atmosphere. It seems probable that this zinc vapour could, by displacing hydrogen, lower the concentration of hydrogen in the weld metal. A simpler explanation is that the beads on galvanized plate, being of a different shape (as shown by Fig. 1) give rise to lower contractional stresses and consequently to fewer fissures.

Table III

Results of fissure counts for *E* electrodes

Length of Electrode, in. per in. of weld	*Electrode Size, s.w.g.*	*Plain*		*Galvanized*	
		Energy Input, KJ/in.	*Number of Fissures per sq.in.*	*Energy Input, KJ/in.*	*Number of Fissures per sq.in*
1	12	13·1	780	13·6	55
1	10	14·6	164	17·8	19
1	8	23·3	496	28·1	8
1	6	31·6	443	34·6	14
1	4	48·4	339	42·1	19
1½	12	15·3	441	15·1	—
1½	10	21·9	120	21·9	57
1½	8	33·9	353	33·9	54
1½	6	43·6	—	46·2	12
1½	4	44·6	379	—	95
2	12	23·6	857	22·4	320
2	10	29·5	966	32·4	57
2	8	44·6	299	44·2	7
2	6	60·9	209	59·4	5
2	4	83·5	63	84·8	25



4—*Effect of galvanizing on severity of fissuring (electrode* E)

Tensile Tests

All-weld-metal

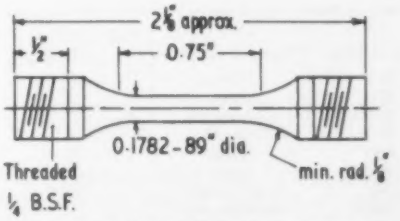
Electrodes *B* (Class *E* 219) and *AO* (Class *E* 616) were used to make ½ in. butt welds. Small specimens were machined to the shape shown in Fig. 5. Three specimens were made for each combination of plate condition and electrode. Conventional tensile tests were carried out, the results being given in Table IV. Two different extension rates were used, but since this factor was found to have a negligible effect, the results may be averaged.

The mean results show that galvanizing has had no significant effect on the tensile strength or ductility of all-weld-metal specimens.

Porosity was apparent in specimens made using the rutile-covered electrodes *B*, for both galvanized and non-galvanized plate. This was probably due to the very large length of electrode deposited per inch of weld, and the electrodes were probably not at fault. Welds made using *AO* electrodes were apparently free from porosity.

Parallel-sided composite specimens

The same electrodes were used to make ⅛ in. close-butt welds. The specimens were ½ in. wide, transverse



5—*Dimensions of all-weld-metal tensile specimen*

Table IV

All-weld-metal tensile tests

Weld No.	*Electrode Code*	*Plate Treatment*	*Extension Rate, in./min*	*Tensile Strength, tons/sq.in.*	*Elongation on* $4\sqrt{A}$, %	*Red. in Area, %*
Individual Results						
182	B	None	0·2	30·6	28·6	38·2
181	B	None	0·2	31·0	16·0*	39·9
181	B	None	0·025	31·2	27·0	40·6
179	B	Galvanized	0·2	30·2	27·0	44·6
178	B	Galvanized	0·2	30·9	23·8	46·7
178	B	Galvanized	0·025	30·5	14·3*	49·5
185	AO	None	0·2	33·7	28·6	66·0
184	AO	None	0·2	32·2	34·9	65·0
184	AO	None	0·025	31·3	33·3	64·8
166	AO	Galvanized	0·2	32·9	33·3	58·5
173	AO	Galvanized	0·2	32·0	31·7	66·4
173	AO	Galvanized	0·025	33·8	28·6	66·4
Mean Results						
	B	None		30·9	27·8	39·4
	B	Galvanized		30·5	25·4	45·7
	AO	None		32·4	32·3	65·3
	AO	Galvanized		32·9	31·2	63·8

* Specimen noticeably porous

to the welding direction. The welds were smoothly ground flush with the plate surface; 16 tests were carried out, four for each electrode and plate condition. All specimens broke far away from the weld, irrespective of the electrode used, and whether or not the plate had been galvanized; the tensile strengths ranged from 20·2 to 27·1 tons/sq.in. None of the welds showed any visible surface defect.

'Waisted' composite specimens

The welds were made as for the parallel-sided tests. Flat specimens of the shape shown in Fig. 6 were taken transverse to the welds. These were shaped so as to induce failure in the weld metal. The tensile strengths obtained are given in Table V and indicate slightly inferior strength for the welds made in galvanized steel using *B* electrodes. However, all the welds were considerably stronger than the mild steel plate. Ductility was not measured, but in all cases it was observed that considerable plastic deformation of the weld took place before failure.

Bend Tests

These were carried out to compare the ductility of welds in plain and galvanized $\frac{1}{8}$ in. mild steel sheet. The weld reinforcement was ground off both sides of the specimens, the final thickness being approximately 0·1 in.

The method of bending was to press the specimens into a thick block of lead-tin alloy with a hardened steel former of the desired radius. This technique ensured that the specimen closely followed the contour of the former.

Transverse tests

These specimens were 2 in. long × $\frac{1}{2}$ in. wide with the welds running across the specimens.

For each of two electrodes (*B* and *AO*), and for plain and galvanized sheet, one specimen was bent with the face of the weld in tension and one with the root in tension. All eight specimens were bent to 180° around a former of $\frac{5}{16}$ in. radius without any sign of cracking. This demonstrates a satisfactory ductility for the weld metal.

Longitudinal tests

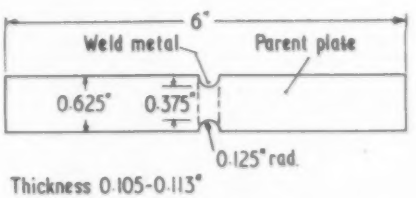
These specimens were 2 in. long × $\frac{3}{4}$ in. wide with the weld running lengthwise centrally down the specimen. Thus by bending, the ductility of plate, heat-affected zone, and weld metal could be tested simultaneously.

Using *AO* electrodes, no cracking was observed in any zone, for either plain or galvanized plate, and the specimens withstood a bend of 180° around a former of $\frac{5}{16}$ in. radius. Using *B* electrodes, slight cracking occurred in the weld metal after bending to only 60° around a former of $\frac{3}{8}$ in. radius. This cracking was

Table V

'Waisted' tensile tests

Electrode Code	*Plate Treatment*	*Tensile Strength, tons/sq.in. Individual*	*Mean*
B	None	37·3	37·2
B	None	37·1	
B	Galvanized	32·2	32·9
B	Galvanized	33·7	
AO	None	37·3	37·2
AO	None	37·1	
AO	Galvanized	37·0	37·1
AO	Galvanized	37·2	



6—*Dimensions of 'waisted' tensile specimen*

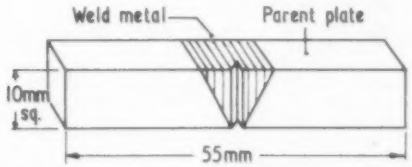
probably due to some small defects in the welds, and was present in welds in both plain and galvanized sheet.

It may be concluded that galvanizing did not affect the ductility of mild steel welds made under the conditions adopted in these tests.

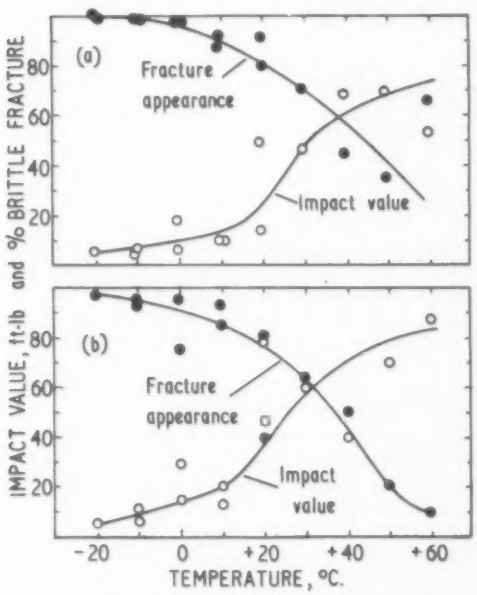
Impact Tests

Comparative tests were carried out using $\frac{1}{2}$ in. butt welds in galvanized and plain mild steel, made with one batch of electrodes *AO*. The Charpy **V**-notch impact specimen was chosen, the notch being placed in the side of the weld as indicated in Fig. 7.

A Losenhausen impact testing machine was employed to carry out tests at various temperatures from −20° to +60°C. The impact values obtained for the two materials are given in Fig. 8. The fractured surfaces



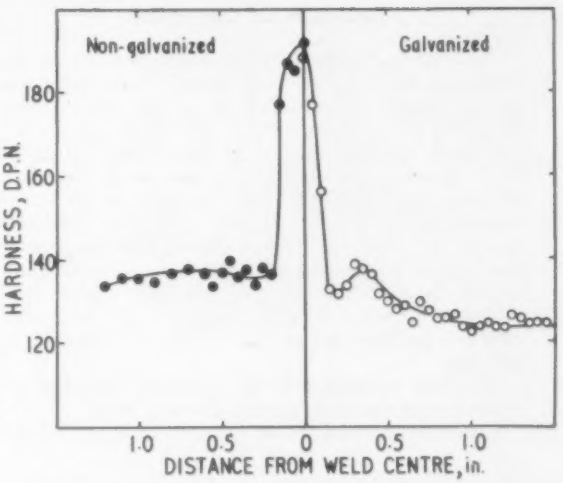
7—*Position of notch in impact specimens. (Notch 2 mm deep, 0·25 mm root rad., 45° included angle)*



8—*Effect of temperature on impact value and appearance of fracture of Charpy* **V**-*notch specimens:* (a) *Plain plate;* (b) *galvanized plate*

were examined by an experienced observer, and the percentage of the area containing visible cleavage facets were noted. These are plotted on the same graphs as the energy absorption data.

From a comparison of Figs. 8*a* and 8*b* it appears that galvanizing lowers the temperature of transition



9—*Comparison of hardness traverses for welds in plain and galvanized mild steel*

from ductile to brittle behaviour by about 5°C. This represents a slight improvement over the weld in plain steel, but in view of the high scatter (normally found for this type of test), it is doubtful whether this small difference is significant. However, the results do indicate that galvanizing is not detrimental to the impact properties of weld metal.

Hardness Tests

Hardness tests were carried out with the object of finding the effect of galvanizing on the hardness of the weld metal and of the heat-affected zone. Transverse sections were taken through welds in $\frac{1}{8}$ in. mild steel sheet made with *B* electrodes (one pass from each side of the sheet). Vickers hardness tests with a load of 5 Kg were made along the transverse sections and running through the second pass of the weld. An example of the results obtained is given in Fig. 9, which has been arranged to permit a ready comparison between the galvanized and plain materials. This diagram shows that the hardnesses of the weld metals and heat-affected zones for the two materials are very similar. The hardness of the as-galvanized plate is slightly lower, probably due to a softening effect during galvanizing. Apart from this, the other differences are within the limits of experimental error.

Additional hardness tests were also made in both runs of weld metal, with the following results:

	Plain	*Galvanized*
Run 1	178, 172, 178 } 176	177, 177, 174 } 176
Run 2	182, 187, 182 } 184	190, 182, 185 } 186

The second runs are harder than the first, which is to be expected, but galvanizing has had no significant effect on the hardness of either.

Discussion and Conclusions

None of the mechanical tests has shown any serious detriment due to galvanizing. Parallel-sided composite tensile specimens all ruptured in the plate, remote from the weld. Composite tensile specimens, which had been specially shaped to induce fracture in the weld showed, for one of the two electrodes used, inferior tensile strength for the welds in galvanized plate (although still better than the parent mild steel plate). No other detrimental effects of galvanizing on mechanical properties were observed. All-weld-metal tensile, bend, and hardness tests were unaffected, whilst in Charpy tests the notch-ductile to notch-brittle transition temperature was not significantly affected.

The most striking effect of galvanizing was in reducing the incidence of fissures in the weld metal.

Galvanizing appeared to have no observable effect on microstructure, but the weld contour was altered and welding was more difficult. Inferior results were obtained in the hot cracking tests, although the impairment due to galvanizing was not serious.

Acknowledgment

This work was done in the laboratories of the B.W.R.A. for the Technical Committee of the Hot Dip Galvanizer's Association, and was supported financially by that Association.

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1. P. W. Jones: *Brit. Welding J.*, 1957, vol. 4, pp. 189–197.
2. A. F. Flanigan and M. Kaufman: *Welding J.*, 1951, vol. 30, pp. 613s–622s.
3. R. M. Imboden and R. S. Sibley: *Trans. Electrochem. Soc.*, 1942, vol. 82, pp. 227–239.

APPENDIX

Observations relevant to the welding of galvanized steel

(Prepared in co-operation with the Hot Dip Galvanizer's Association)

Fuming

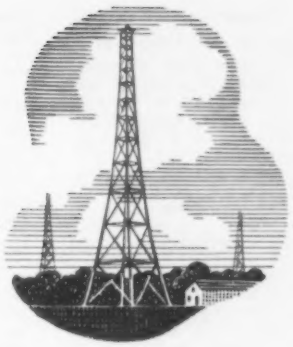
When metal arc welds are made in galvanized steel the heat of welding causes volatilization and oxidation of the zinc coating adjacent to the weld and results in serious fuming. Although this may sometimes be tolerated for outdoor work, adequate ventilation must be provided for welding in confined spaces. An extraction fan is normally required with a hood held within inches of the work so that fumes are drawn directly into the extraction system. Various possibilities also exist for minimizing the occurrence of fumes, such as the provision of chill bars close to the weld, or the use of welding techniques which give small weld pools and a limited spread of heat.

After-treatment of the weld zone

The removal of zinc by volatilization from the weld zone means that some form of after-treatment of the weld area is necessary to restore the protective coating. To obtain a degree of corrosion protection comparable with that provided by the original galvanized coating, zinc may be sprayed or painted on to the weld area after preliminary cleaning, such as the removal of welding slag. The thickness of the sprayed or painted zinc should be similar to that of the original galvanized coating, and the zinc-rich paints used should contain 92–95% metallic zinc in the dried film.

If conventional paints are used to protect the weld area it is important to remember that, because of the overlap, they should be compatible with the galvanized surface. Without prior treatment of a freshly galvanized surface (such as phosphating) difficulties of relatively poor paint adhesion may arise. The zinc-dust/zinc-oxide paints and also paints pigmented with calcium plumbate will, however, adhere well to freshly galvanized surfaces without any pretreatment, and such paints are to be recommended if the treatment of the denuded zone is to be restricted to a simple paint scheme.

NEWS
and Announcements



News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

Spring Meeting, 1959

There has been a small modification to the programme of Works Visits for the Spring Meeting, as published in the March issue of the *Journal*.

Instead of the visit to British Oxygen Research and Development Ltd., on Tuesday 21st April, it has been kindly arranged by British Oxygen Gases Ltd. that the visit to Cricklewood (Thursday 23rd) will include interesting items relating to electric arc welding (mounted by Quasi-Arc Ltd.), and also exhibits to give some idea of the range of fundamental research on welding undertaken by the British Oxygen Group of Companies.

Members are reminded that the closing date for enrolment for the Meeting is 11th April. The list of reservations for hotels is already closed.

Second Annual Lecture

The Second Annual Lecture was given at the offices of the Institute on Thursday, 12th March.

In the unavoidable absence of Sir Leonard Owen, the Lecture was read by Dr. A. B. McIntosh, Head of Laboratories of the Industrial Group of the U.K.A.E.A., who was introduced by the President, Mr. John Strong. A very appreciative audience of about 120 members and visitors listened to Sir Leonard's review of the application of welding to the nuclear engineering programme in Britain.

The Lecture dealt in the main with two fundamental aspects of welding in nuclear plant—the design and fabrication of fuel cans, and the fabrication and inspection of the containing vessels. The development of various forms of can, made from magnesium, aluminium or beryllium, was described. and the need for absolute certainty of leak-proofness was emphasized. With the development of suitable welding techniques a remarkable degree of perfection had been achieved. Various types of fuel can and of welded joints were illustrated.

Turning to the pressure vessels that were needed to contain the nuclear pile and heat-exchangers the lecturer drew attention to the fact that designers and contractors had been called upon to produce vessels of a size and thickness that had never before been considered. He remarked on the need for extreme caution in designing these vessels and for the choice of a material that provided adequate notch toughness. There had to be an assurance of absolute safety, and for that reason vessels were stress relieved and all welding was thoroughly inspected by both radiographic and ultrasonic methods.

Sir Leonard's comprehensive survey of the welding aspects of this relatively new industry was a fine tribute to the remarkable progress that had been made by metallurgists and engineers in finding solutions to the many seemingly impossible problems involved.

A vote of thanks to Dr. McIntosh, proposed by Mr. E. Fuchs, was warmly supported by the audience.

It is intended that the text of the Lecture will be printed in the May issue of the *Journal*.

Mr. A. C. Hartley

At the Council meeting held on 12th March it was learned with regret that Mr. A. C. Hartley, C.B.E., had tendered his resignation from the Vice-Presidency of the Institute, because of the pressure of other commitments. His resignation was accepted with the hope that he would be able to return after the completion of his period of office as President of the Institution of Civil Engineers.

Sir William Larke Medal, 1958

The Sir William J. Larke Medal for 1958 has been awarded to Mr. H. D. Archbold for his paper '*Welding of the Deckhouses of the* Bergensfjord', which was published in the January 1958 issue of the *Journal*.

The medal is the Institute's highest award, and was instituted by Past-President Sir William Larke. It is given annually to the author(s) of the paper judged to be the best presented to the Institute in the year.

The award will be made during the proceedings of the Spring Meeting in London.

Welding Consultants

The Library and Information Service is proposing a revision of its List of Consultants. The Secretary would be grateful for news and details from any member of the Institute who is now practising as a Consultant.

SCHOOL OF WELDING TECHNOLOGY

The following courses are offered by the School in April:

D.9/2 **Health and Safety in Welding**

This course has been organized twice previously, and on both occasions it was designed principally for nurses and safety officers. This time it is being designed specially for supervisory staff.

In April 1960, it is planned to arrange a similar course, but it will be designed specially for nursing sisters in industry.

D.8/1 **Welded Structures**

This is a repeat of the course originally held in April 1958, but on this occasion it is being planned specially for designers.

The programmes of these courses are given in the School prospectus, which can be obtained from the Secretary.

NEWS OF MEMBERS

H. C. Cotton has relinquished his post as Technical Manager of the Arc Manufacturing Co. Ltd., Glasgow, to join the British Petroleum Co. Ltd., at Beaufort House, London, as Welding Superintendent.

H. West has been appointed Assistant Managing Director of Metropolitan-Vickers Electrical Co. Ltd. Joining the company in 1918, Mr. West became chief engineer of the motor and welding department in 1940, and in 1949 chief electrical engineer. Appointed to the board in 1951 as director of electrical engineering, Mr. West has travelled extensively for the company in South Africa, the Middle East, Russia, the Continent and North America. He is also managing director of the John Thompson Nuclear Energy Group, chairman of Nuclear Graphic Ltd., and director of Beyer Peacock Ltd., Sunvic Controls Ltd., and Isotope Developments Ltd.

G. R. Bell has been appointed General Manager of the British Division of Wall Colmonoy (Canada) Ltd., and will be responsible for the Company's entire European operations.

Obituary

The Council regret to record the death of:

Fred Wood, founder and Managing Director of Yorkshire Engineering and Welding Co. (Bradford) Ltd., on 1st February. Mr. Wood was formerly Works Manager and a Director of W. P. Butterfield Ltd., Shipley.

Adrian H. D. Burnett of the North London Branch (Member 1944).

E. Randall (Assoc., Sheffield and District Branch).

His many friends among Members of the Institute will have learned with sympathy of the bereavement suffered by **Rex Thomas**, whose wife died suddenly at the end of January.

CONTRIBUTOR TO THE JOURNAL

F. Watkinson, B.Sc.(Eng.), L.I.M., Research Officer with the British Welding Research Association, was educated at Kilburn Grammar School, and continued his technical studies at Battersea College of Technology. He obtained a London University degree in Metallurgy in 1953, and in the same year he was elected a Licentiate of the Institution of Metallurgists.

F. Watkinson

Mr. Watkinson is in the Ferrous Section of the BWRA Metallurgical Laboratories at Abington, and is working on the problem of the weldability of low-alloy steels. Previously he had been concerned with the welding of reactive metals.

BRANCH NEWS—Reports of Meetings

East Midlands — Metal Spraying

At the December meeting, held in Nottingham, a paper on "The Scope and Limitations of Metal Spraying" was given by R. Gallagher. In reviewing the history and development of metal spraying, he said that although the technique was first used commercially in Great Britain in 1922, it did not become popular until the thirties. He gave details of the apparatus used, describing metal spraying as the fabrication of coatings against corrosion, as well as a process for decorative purposes. Mr. Gallagher pointed out that, broadly speaking, any coating can be applied to any surface at any site—but at a price. Shot blasting of a surface is necessary to remove scale and provide a roughened surface for the receipt of the sprayed metal.

He stressed that it was this need for shot blasting that made the setting up of a plant for protective coating an expensive business, for the "pistol" itself cost only about £200–250. It was, he suggested, possibly for this reason that the best known field for metal spraying is that of repairing worn machine parts. He emphasized that when preparing for the building up of a worn shaft by machining it is advisable to use a sharp tool and to employ negative rake, causing "chatter" intentionally, and thus producing a suitable surface for adhesion of the sprayed metal. Mr. Gallagher also mentioned the spraying of non-metals, including polythene, synthetic rubber, bitumen, and nylon. K.H.E.

Chemical Plant

The January meeting was held in Derby when Mr. M. Birkhead presented a paper on "General Considerations in the Welding of Materials for Industrial and Chemical Plant", his opening remarks being devoted to the training of welders at his own Company. Passing to the welding of mild steel, the speaker said that the difficulties experienced are related to the metallurgical characteristic of the material. He stressed that electrode manufacturers were continually introducing new electrodes to overcome faults in steels, mentioning too, low hydrogen and iron powder electrodes.

Turning to automatic welding, Mr. Birkhead emphasized that whether open-arc or submerged-arc was used the fit up, cleanliness, voltage setting, and position of seams are of the utmost importance. In referring to stainless steels, he stressed that many difficulties might occur if consideration was not given to precise working conditions and that the steelmakers' recommendations should be treated only as guidance. He also made brief mention of the welding of nickel, nickel alloys, and clad steels.

Among a number of slides shown throughout the talk were those illustrating that bead and crater cracking in a weld made with rutile electrode were not apparent with the same type of weld made with a low hydrogen electrode; and one of a 'fish-eye' caused by hydrogen in a weld. Others included the tipping of a heavy boring tool using the weld deposit from a low hydrogen electrode, the tip being forged after the building up process; and joint preparations for various metal thicknesses. Here it was mentioned that distortion problems are greater with the welding of stainless steels due to the higher coefficient of expansion and contraction. K.H.E.

Leeds — Fabrication of Pressure Vessels

The subject of Mr. W. Weightman's lecture at the fifth meeting of the session, on 21st January—the manufacture of a fusion welded pressure vessel—proved to be of tremendous interest to more than seventy members and friends.

The speaker described how his Company had changed from riveting to welding for the manufacture of boilers and marine equipment. This had involved considerable alterations to the works to satisfy the conditions of Lloyd's Register, but by 1951 the Company was in a position to undertake approved Class I work.

Mr. Weightman emphasized the need for thorough preparation of material and careful inspection at every stage of manufacture, from the ultrasonic testing of plates for laminations to the final X-ray examination of the welded seams. This was demonstrated by a number of very clear slides showing the great care taken in the preparation of plate edges for welding, and the pressing of shell plates and ends.

The lecturer's remarks provoked a long and very interesting discussion. C.B.

Liverpool — Good Penetration

In spite of transport paralysis, caused by fog clamping down on Merseyside, there were quite a number of stalwarts able to get to Byrom Street on 13th January to hear Mr. D. T. Carter present a lecture on inspection of welding. The lecturer made it clear at once that he considered weld inspection in all its various phases to be of vital importance. Often it is applied too late—when the work is finished. Instead, it should be a step by step process, including the examination of the equipment to be used as well as the material and the weld preparation. Mr. Carter then described in detail various methods of inspection, and illustrated their applications by showing various faults in welds. He considered that visual inspection of all parts should be a first step, and this should be followed by the most suitable non-destructive examination for the intended service of the fabrication. He also gave details of several conventional methods of weld testing.

The ensuing discussion, though brief, indicated clearly that most attention should be given to inspection before and during welding rather than after work had been completed. The costs and hazards of X-ray and isotope examination were considered, and some useful guidance was given by the lecturer. H.R.C.

Manchester — Welding Stainless Steel

The second half of the Session was opened on 7th January with a paper on "Fabrication in Stainless Steel" by Basil Banks. He began by pointing out that although the term 'stainless steel' was in common use today, few people appreciated the wide variety of materials which it covered. In describing the many different types of stainless steel, he dealt with their characteristics and uses as well as their advantages and limitations; the metallurgical details of certain basic types and the "why and how" of the use of the different stabilizing elements. Mr. Banks continued with the various welding processes used in the fabrication of stainless steel and explained the difficulties encountered with distortion, showing examples of these problems and the methods of overcoming them. In conclusion, he showed a number of large

stainless steel fabrications which had recently been completed for such divergent uses as atomic energy and beer brewing. The discussion that followed dealt with the possibilities of difficulties arising when the stabilizing elements used in the parent material and the electrodes differ; the different methods for descaling dished ends after hot forming; and improvements to existing welding methods, including the use of submerged-arc welding for the thicker stainless steel vessels. J.M.W.

Inspection Methods

On 2nd February Mr. D. T. Carter lectured on weld inspection, and illustrated his remarks with a number of slides. Among the inspection methods he described were visual examination before and after welding, pressure testing, fluorescent and dye penetrant examination, magnetic particle, radiographic, and ultrasonic detection.

Mr. Carter emphasized that the inspection procedure should be related to expected service conditions, and that in many instances the more expensive forms of inspection were not really necessary.

In reply to a question on what method could be used on plates thicker than 4 in. Mr. Carter considered that linear accelerators would eventually be used; an alternative available method was to make an examination after part of the weld had been completed; but this would involve the extra cost of further preheat. For fillet inspection it emerged that an ultrasonic apparatus with miniature probes was being developed, which would be especially suitable for small fillets.

Some members of the audience gave differing views and experiences on the magnetic crack detection of fillet welds, particularly in relation to surface dressing before testing. J.W.A.

South London **Gas Shielded Welding**

At a very well attended meeting on 8th January, Mr. A. A. Smith gave a lecture on the practical significance of BWRA work on gas-shielded welding processes.

After briefly outlining the various types of processes, Mr. Smith concentrated on inert-gas metal-arc welding, and differentiated between the various methods of arc regulation in terms of the power source characteristics and burn-off characteristic of the filler wire.

He gave a description of an exploration of the process as used for aluminium over a large range of current—work carried out in conjunction with ERA. The restriction on the process at low currents by the reversion of spray type metal transfer to sub-threshold or globular type transfer was contrasted with the deterioration of the process at high currents with the incidence of puckering. The lecturer then described BWRA work which had resulted in the development of special nozzles that enabled satisfactory welds to be made at high currents without the occurrence of puckering. These nozzles use an auxiliary argon supply, and it has been possible to weld 1 in. thick pure aluminium at 500 amp without the need for back chipping.

Mr. Smith then discussed ways of overcoming the problems involved in the sub-threshold change at low currents, and showed the burn-off characteristics and metal transfer frequency curves for a range of wire diameters. From these data it was concluded that the lowest practical welding current decreased proportionately with the diameter of the wire; with 1/64 in. dia. wire it was possible to operate at as low as 50 amp and yet obtain spray transfer. A small 'gun', shown in the accompanying illustration, had been developed for the experimental welding of aluminium sheet with small diameter aluminium wires. The driving motor is housed in the handle of the gun and pulls the wire from the reel. The value of such equipment for welding this material, compared with the argon tungsten arc process, was apparent where access was restricted and for high speed welding of laps and fillets.

Work done by BWRA on CO_2 shielded metal arc welding of mild steel was also discussed, and reasons were given for the various additions to wire compositions, as well as the effect of using different gas compositions on the arc characteristic. Mr. Smith also referred to the effect of various welding conditions on metal transfer frequency and illustrated the connection between spatter and arc voltage. He outlined the advantages of using a constant potential power source characteristic and described the effect of reducing wire diameters for welding thin material. Since an increase in electrode extension and current would result in decreased penetration it was evident that manual skill was still important in this process, even though it is semi-automatic.

The lecture promoted a stimulating discussion, and particular interest was shown in the developments in welding with thin wires.

Welding gun for thin wire welding

Medway Section—Argon Spotwelding

Argonarc welding, with special reference to spot welding, was the theme of the lecture and demonstration given at the Medway College of Technology on 28th January.

The lecturer, Mr. Murrell of British Oxygen Gases Ltd., spoke of the basic principles of the process and its applications in industry. He followed his talk with a very practical demonstration, which included the spot welding of stainless steel. Some samples of this form of attachment, made from a variety of materials were also on show.

Interest, shown by the 55 members and visitors attending, was obvious by the open discussion that followed the demonstration.

Wolverhampton **Welding in Light Engineering**

The second half of the 1958/59 Session began on 21st January, with a talk on "Resistance Welding and Brazing in Light Engineering" by Mr. E. V. Beatson.

Mr. Beatson's remarks applied mainly to large quantity production, and he emphasized at first a number of points in connection with the detailed design of components, which must be absolutely correct for the chosen joining process.

Several different methods are usually available for economical production, but the best could only be determined by a detailed analysis of all the requirements. In the mass-production industries the three main needs were: Maximum output per operator hour; best use of unskilled labour; and the reduction of the number of subsequent finishing operations.

These conditions were best met by resistance welding or brazing methods, but it should be remembered that good methods might soon become outmoded and old ones so developed that they once again become economical. For production men to be kept informed of latest developments it was essential that reference should be made to the specialist when a new project is considered. Good team work between research, design, and planning staff was invaluable.

Developments since the war had been mainly in speeding up known processes: Examples were the making of several welds simultaneously; the use of more than one transformer for multi-spotwelding; improved methods of handling and discharging components; combination of the welding with some other production process in the one machine; and the use of conveyors to achieve automation. Mr. Beatson illustrated these points with a number of slides, ranging from the use of normal manual spot welding to elaborate fully automatic machines for completing car body components in one operation. Production rates on some of the machines shown were as high as 800 components an hour, though this high degree of automation with its consequent great capital cost, could not be justified unless the demand for the product was sufficiently high.

In regard to brazing, Mr. Beatson mentioned three methods commonly used in large quantity production: Furnace brazing in a reducing atmosphere at about 1130°C., with copper as the usual brazing medium; high-frequency heating; and resistance

heating. The joint design was always important, whatever method was used, so that the parts could be held in the correct positions and to permit proper capillary flow. It was unfortunate that these conditions were not always compatible with the best engineering design.

Typical applications of brazing were illustrated, including refrigerator components and a finned condenser in which 670 joints were completed simultaneously.

Mr. Beatson concluded a most absorbing lecture by showing a solenoid assembly in which a number of different brazing and welding processes were combined to give an economical and adaptable result at production rates of 20–30,000 per week.

After an interesting discussion in which Mr. Beatson gave some helpful replies to questions, a hearty vote of thanks was proposed. Some arc welders among the audience left with the hope that the distressing complaint of 'arc-eye' might one day become a thing of the past! B.K.B.

BRITISH WELDING RESEARCH ASSOCIATION

Translations from the Russian

In the past few issues of the *Journal* there have been published translations of articles from Russian welding periodicals, prepared for the Association. As announced in the February issue (p. 81) there is to be a programme of translations from one periodical *Avtomaticheskaya Svarka* to include all articles published in each monthly issue. In addition to these services the Association is now providing for its members a series of 'separate' translations of selected articles published in various languages. They will deal mainly with metallurgical or scientific subjects rather than welding processes.

These separate translations are being printed and will be available to Association members by prior arrangement. But there is some possibility that spare copies of a few translations may be available to others. There can be no guarantee that copies can be supplied, but anyone interested is asked to apply to the Publications Department of the Association, 29 Park Crescent, London, W.1.

Translations that have already been prepared are:

TR4: Fatigue strength of welded joints in MSt.3 steel containing up to 0·15% As, *by A. E. Asnis.*

TR5: Fully austenitic weld metals resistant to hot (solidification) cracking, *by B. I. Medovar and Yu. V. Latash.*

TR6: Determination of composition of steel weld metal by electric spark sampling, *by E. S. Kudelya.*

TR7: Influence of low temperatures on the impact tensile strengths of welded joints, *by Yu. P. Sataev.*

TR8: Electron microscope examination of welds in titanium, *by V. F. Grabin and S. M. Gurevich.*

TR9: Formation of hot cracks in the arc welding of austenitic steels, *by K. V. Lyubavakii and V. A. Toropov.*

TR10: Mechanics of formation of hot crack in the welding of Cr–Ni–Nb austenitic steels, *by B. I. Medovar.*

TR11: Reasons for reduced fatigue strengths of welded joints in low alloy steels, *by A. E. Asnis.*

TR12: Welding without preheat of alloy steels in the chemical industry, *by W. Gilde.*

TR13: Fine structure (granular and subgranular) and its influence on the impact strength of welds, *by B. S. Kasatkin, L. Kareta and D. F. Darovskii.*

TR14: Deformations caused in H-beams by depositing unsymmetrical vertical weld beads on the web, *by I. P. Baikova.*

TR15: Role of carbide phase: and of primary ferrite in hot cracking during the welding of austenitic steels, *by N. F. Lashko and S. V. Lashko-Avakyan.*

TR16: Prevention of cracking in the welding of *AMTs* aluminium alloy, *by N. D. Portnoi and N. G. Heinrichsdorf.*

TR17: Electrodes for welding heat resisting tube steel *IKh18N12T, by B. I. Lazarev.*

TR18: Calculation of deformations of members when applying two fillet welds simultaneously, *by N. O. Okerblom and V. N. Savelev.*

TR19: Selection of basic parameters for condenser buttwelding, *by N. S. Siunov and M. A. Sergeev.*

TR20: Strengths of welded joints under separate actions of residual stresses and local plastic deformations, *by D. I. Navrotskii.*

TR21: Tests for the strength of members with abrupt changes in shape at low temperatures and in different states of stress, *by D. I. Navrotskii.*

TR22: Determination of tangential stresses in butt welds, *by D. I. Navrotskii.*

TR23: Influence of flux composition on the reduction of Si and Mn during automatic welding of mild steel, *by M. D. Shchipkov.*

INTERNATIONAL INSTITUTE OF WELDING

The First Ten Years

Copies of the review of the activities of the Institute over the past ten years—"IIW-IIS 1948–1958" are still available from the offices of the British Institute of Welding.

A brief outline of the contents of this most useful reference book was given in the September 1958 issue of the *Journal* (p. 439).

Multilingual Collection of Terms

A third part has just been issued to this valuable series of terms for welding and allied processes in twelve languages. It deals with Arc Welding. The terms adopted are those established by common usage in each country.

The indexing follows the style of previous parts (which dealt with Gas Welding and with General Terms for Welding Procedure, Characteristics, and Inspection of Welds) and allows easy translation of a term or expression from one language to another.

This publication is also available from the British Institute of Welding.

OTHER SOCIETIES

Moscow Conference on Automatic Control

It is announced by The British Conference on Automation and Computation that the First International Congress of the International Federation for Automatic Control is to be held in Moscow in June–July 1960.

Details of the Congress can be obtained from the Hon. Secretary, B.C.A.C., c/o The Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.

The Pipeline Industries Guild

The Guild was set up in November 1956 to form an organization to develop the science and practice of pipeline design, construction, and operation, and to afford a means of communication between interested bodies and individuals.

Those interested in the aims of the Guild should write for further details from the Secretary, Mrs. M. H. Shields, 7 Iddesleigh House, Caxton Street, London, S.W.1.

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee now invites applications for the award of 1959 Fellowships.

Applicants will be required to define the programme of training they desire, and to give particulars of their education, qualifications, and previous career. Full particulars and forms of application can be obtained from the Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1. Applications are to be made before 1st June 1959.

NEWS FROM INDUSTRY

Essay Competition

For the seventh year in succession *Research* (Butterworths Scientific Publications), is sponsoring the Waverley Gold Medal Essay Competition.

This Medal, together with £100, will be awarded for the best essay of about 3000 words describing a new scientific project or practical development. There will also be two other prizes worth £50.

The competition is open only to persons engaged in scientific work from 1st January to 31st July 1959.

More details can be obtained from the Editor of *Research*, 4–5 Bell Yard, London W.C.2.

British Iron and Steel Industry Translation Service

The Iron and Steel Institute announce that a translation of any article on iron and steel manufacture in the foreign technical press can now be provided at a fraction of the translating cost, if three requests for it are received by the Service. The Service is run by the Institute with the collaboration of several large companies and of the British Iron and Steel Research Association. Some

530 translations are already available, a large proportion from German or Russian.

Requests for new translations are invited from all, members and non-members alike, in Great Britain and abroad. Anyone requiring a translation should send a request to B.I.S.I.T.S., who will check that no translation already exists and then circulate particulars to members (and some others). If further requests are received, B.I.S.I.T.S. will commission a translation; if only one other company is interested, it and the original enquirer are invited to share the cost of translation. When no other requests are received, B.I.S.I.T.S. can arrange a translation privately; if it is needed urgently it is made at once, without waiting for this procedure.

A complete list of the first year's translations, classified by subject, is now available; it is kept up-to-date by fortnightly lists (with classified cumulations every six weeks). All translations are also listed in the Journal of the Iron and Steel Institute and in B.I.S.R.A. Report Lists. In addition, lists of translations in preparation are issued, to notify in advance those who themselves make translations. Several technical journals list translations of particular interest to their readers. It is, however, not advisable to rely on these lists as a complete guide to the foreign literature; the abstracts and indexes in the J.I.S.I. provide a comprehensive survey, on the basis of which enquiries for translations may be made. B.I.S.I.T.S. maintain a card index of translations made by several other organizations in Great Britain, the U.S.A. and (for translations from Eastern languages) Germany and France.

Enquiries are welcomed and should be addressed to the British Iron and Steel Industry Translation Service, The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

Stud Welding for Composite Construction

Readers of the article on Structural Applications of Stud Welding, by R. W. Taylor and J. C. Chapman, published in the March issue of the *Journal*, may be interested to have more details of composite construction, referred to in the second part of the paper. The following short bibliography has been supplied by the authors; it could not be included at the end of the paper as published:

F. G. THOMAS and A. SHORT: Laboratory investigation of some bridge deck systems *Proc. Inst. Civil Eng.*, 1952, vol. 1, pt. 1.

R. H. WOOD and R. J. MAINSTONE: Stress measurements in the steel frame of the new Government Buildings, Whitehall Gardens. Paper No. 6, Conference on the Correlation between Calculated and Observed Stresses and Displacements in Structures. *Inst. Civil Eng.*, 1955.

N. M. NEWMARK and C. P. SIESS: Research on highway bridge floors at the University of Illinois, 1936–1954. *Univ. Ill. Eng. Exp. Stat.* Reprint Series No. 52, 1955, vol. 52, No. 41. Jan.

G. WASTLUND and L. OSTLUND: Studies of composite beams. 4th Congress, Int. Assn. Bridge Struct. Eng., 1952.

G. B. GODFREY: Post war developments in German steel bridges and structures. *J. Inst. Struct. E.*, 1957, vol. 35, No. 2, Feb.

W. C. ANDREWS: Composite construction. 50th Anniv. Conference, Inst. Struct. E., 1958, Oct.

R. JONES: Composite action in steel framed, concrete encased, multi-storey buildings. *ibid.*

The opportunity is taken to give acknowledgement to the following organizations for the use of illustrations that accompanied the article:

The Steel Company of Wales Ltd.; W. S. Atkins & Partners; Cleveland Bridge Engineering Co.; General Engineering (Stalybridge) Ltd.; and Petro Carbon Ltd.

Wire and Sheet Gauges

As a result of extensive enquiries (see the December issue of the *Journal*) the B.S.I. Committee MEE/-/7 has given further consideration to this problem. Their first decision was that the s.w.g. is too well established to be supplanted, at least in Britain, and it was recognized that there was little hope of the s.w.g. becoming established as an international series under ISO auspices. Nor was the importance of the present draft ISO proposal overlooked. This suggests that the method of designating the thickness of sheet or diameter of wire should be by stating the basic size in millimetres followed (if desired) by the letter "U" to indicate that this size belongs to the international series. The Committee intend to consider the domestic position on the use of wire gauges in the near future. They would like to see published a British Standard giving full information on the ISO metric series as well as the series of gauges at present in general use in this country, and giving some clear guidance that may lead to a greater concentration of U.K. usage on the s.w.g. and b.g.

Automatic welding replacements

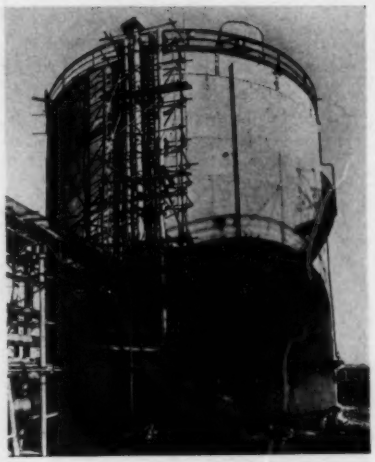
To enable customers to reduce capital expenditure and to save time usually lost in reconditioning Quasi-Arc Ltd. have introduced a scheme for the replacement of their automatic welding machines that are not more than nine years old.

The scheme applies to self-propelled Fusarc and Fusarc/CO_2 machines and fully reconditioned machines of the latest Mk.III type will be delivered immediately from stock. They carry the normal 12-month guarantee of the Company. The price of the service will depend largely on the age and model of the machine and not on its condition.

Aluminium tanks for methane storage

Recently, the first tanker load of liquid methane arrived in Britain in the specially converted vessel *Methane Pioneer*. The liquid is to be stored at Canvey Island for the North Thames Gas Board in insulated aluminium tanks. One of these, illustrated here, was constructed by the A.P.V. Company, who also supplied 2000 ft of 10 in. dia. insulated aluminium pipeline to convey the liquid methane from the ship to the storage tanks. The second of the two 90,000 cu.ft tanks was constructed by Whessoe Ltd.

The properties of some aluminium alloys at the low temperature of liquid methane is the subject of four reports, published in the November 1958 issue of the Journal, which are to be presented and discussed at the Spring Meeting of the Institute this month.



Aluminium tank made by A.P.V. for storing liquid methane

Welding of plastic coated steel sheet

At a private exhibition in London the applications and methods of fabricating Stelvetite plastic coated sheet were demonstrated by the makers John Summers & Sons Ltd.

The material can readily be pressed, formed, and welded without damage to the plastic coating, and several manufacturers of welding equipment demonstrated various ways of joining the material.

Resistance projection welding, with a smooth flat platen against the plastic surface, offers one of the most simple and effective ways of welding metal parts to the steel sheet. With small modifications to equipment stud welding also provides a ready means of attaching various forms of stud.

High-frequency welding can also be used to join decorative plastic materials to the coated side of the sheets. Hot gas welding, using a filler rod of the same material as the coating, makes an effective sealed joint between coated surfaces and provides a moderate mechanical strength.

Welded light-alloy tube

A tube forming machine with high-frequency resistance welding equipment has recently been installed at the Aylesbury works of Elm Engineering Ltd. for the manufacture of aluminium alloy tubes.

The process was developed by the New Rochelle Tool Corporation of New York, and Elm Engineering is the first company in the U.K. to manufacture light alloy tube by this cheaper method.

The present mill is capable of producing tube from $\frac{1}{4}$ to $1\frac{1}{2}$ in. outside diameter in thicknesses of 14 to 22 s.w.g. at speeds of up to 400 ft/min. The material currently used is NS.4 and NS.5 half-hard and soft NS.5 but successful trials have been made with other alloys and with mild steel.

Coiled stip is fed into the mill and passes through eight pairs of forming rolls. In circular form it then passes a seam guide, which controls the weld gap, to the double-pole welding head, and then through a pair of pressure rolls. In the third stage of the machine the weld flash is removed from the outside of the tube, which is then roll straightened and cropped to suitable lengths.

General view of tube mill

Pressure rolls and high-frequency welding head of aluminium tube mill

The high-frequency current is provided from a Thermatool valve oscillator and transformer with an output of 50 kW at 450 kc. The welding head is so placed that the welding temperature is reached just as the unwelded part of the tube enters the pressure rolls.

Finished tubes show uniformity of welding, adequate penetration, and virtually no 'flash' inside the tube. Bending and manipulation can be done without affecting the weld.

The Company consider that equal success is possible with heat-treatable alloys, for the annealed zone is smaller than with other welding processes, and with other metals such as copper and mild steel. Other sections, such as oval or rectangular, could also be made with different arrangements of the forming rolls and welding head.

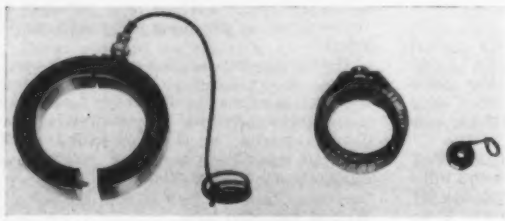
NEW EQUIPMENT AND MATERIALS

Torch Igniter

A new bench unit has been marketed for use with welding, cutting, brazing and soldering blowpipes, metal spraying pistols etc. Produced by A. S. Young & Co. Ltd., it is available at a low price and can be delivered from stock.

Resistance Welding Current Meter

Recently marketed by Hirst Electronic Ltd., the HED Welding Current Meter is designed to measure short pulses of heavy current, as encountered in resistance welding machines. There is no upper limit to the value of current that can be measured but standard instruments have a minimum of 500 amp and a maximum of 100,000 amp over 6 scales. The minimum pulse time is 10 milliseconds but pulses down to 2 milliseconds can be measured if several welds are repeated. The instrument can be used with welding machines employing synchronous, non-synchronous, and energy storage controls. Where phase-shift heat control is incorporated a correction factor must be used to obtain accurate quantitative evaluation of RMS current but a reading can be taken directly for checks of consistency. A standard split and hinged current transformer is normally supplied which will clamp over any bar up to 4½ in. dia. Fixed-ring type transformers can also be supplied for building into individual welding machines and any number can be switched to a meter.



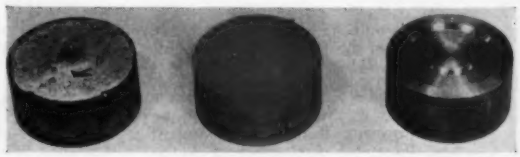
Three standard interchangeable toroids for H.E.D. meter

Earth Clamp

A robust earthing clamp for general use—one of the Interlas range of welding accessories made in Holland—is now being marketed by Courtburn Supplies Ltd. It has a very powerful spring grip and a heavy copper braid connecting the two jaws to obviate arcing and ensure a good earth connection. The clamp complements the range of electrode holders, cable connectors, and super flexible welding cable in the Interlas range.

Automatic hardfacing

Deloro Stellite Limited announce the introduction of a new Sprinkle Fuse process for hardfacing with "Stellite" Powder which has been developed in collaboration with Radio Heaters Ltd. This process, it is claimed, offers many advantages where resistance to abrasion, corrosion or heat is necessary and particularly for valve seatings, seat rings and discs, pump sealing rings and thrust plates. The method employed is simple: the Stellite powder and flux are placed in the recess in the steel blank; the steel is positioned adjacent to the work coil of the Radyne equipment; and push-button heating is initiated with or without rotation of the parts. When the bonding temperature is reached throughout the Stellite layer and the recess, the heating ceases automatically. Deposits are sound and of controlled depth; there is freedom from slag inclusions, blowholes and shrinkage porosity; and maximum hardness is obtained with good adhesion. Welding skill is eliminated by the automatic heat control.



Hardfacing by the Stellite Sprinkle Fuse process

Stainless Steel Piping System

A series of standard parts, 3–8 in. bore, fabricated from corrosion-resistant alloys, and made by Welding Technical Services Ltd. of Birmingham, is finding an increased application for stainless steel flow lines.

'Weltexa' piping includes straights in various lengths, bends and swept bends, tees and standard reducers. The system makes use of a specially designed taft backed by a BS Table D loose flange. Bends are made by welding two half pressings and are completely free from projections. The wall thickness is also uniform.

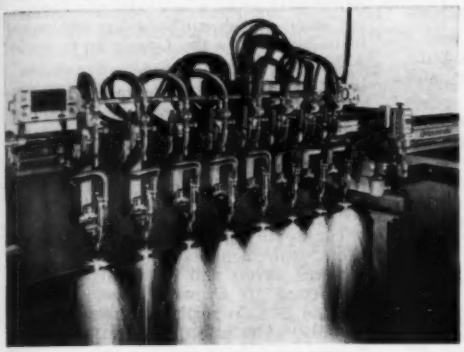
All welding is done by the inert-gas metal-arc process, and is strictly controlled by radiography and other inspection methods.

Large welding transformer

A single-operator wheel-mounted a.c. welding set has been introduced by The General Electric Co. Ltd. to provide a maximum intermittent welding current of 700 amp at 80 V. The continuous rating is 650 amp. Current control is in 25 steps down to 120 amp. The welding set, designated O.T.2, is an oil-immersed single-phase transformer with a separate choke. The components are securely braced against movement during transit, and the unit is mounted on four rubber-tyred wheels, with one pair guided by a towing handle.

Cutting small shapes in sheet steel

An eight-burner version of the popular Hancomatic oxygen profiling machine was recently shipped to an overseas customer by Hancock & Co. (Engineers) Ltd. The machine incorporates the recently introduced solenoid operated gas control valves for speedy large-scale production of small shapes in sheet steel. The new machine supplements an earlier six-burner model, which has been in continuous operation for about a year.



Hancock special-purpose eight-burner oxygen profiling machine

CO_2 bare wire welding

Philips Electrical Ltd. have now introduced their process of CO_2 bare wire welding, which was briefly described by S. Astley in his paper presented at the Autumn Meeting of the Institute (September 1958 issue of *Journal*, p. 389).

The machine is controlled by a single lever, which engages the wire feed and switches on the carriage motor and the welding arc. The arc is self-regulating and it is claimed that the low nitrogen and hydrogen contents of the wire virtually eliminate porosity.

Automatic Fluxing for Gas Welding

Many of the inherent difficulties of manual flux additions—lack of accurate control, entrapment of excess flux, difficult removal of residues, and so on—are avoided by the use of automatic fluxing, which has been introduced by Weldcraft Ltd. Basically, the unit consists of a chamber containing a cotton wick or filter, which is kept saturated with liquid flux. Gasified flux emitted by the wick collects in the top of the chamber, where it is picked up by the acetylene as it passes through on its way to the torch. Only the correct amount of flux is used, welding is quicker, and there is no flux residue.

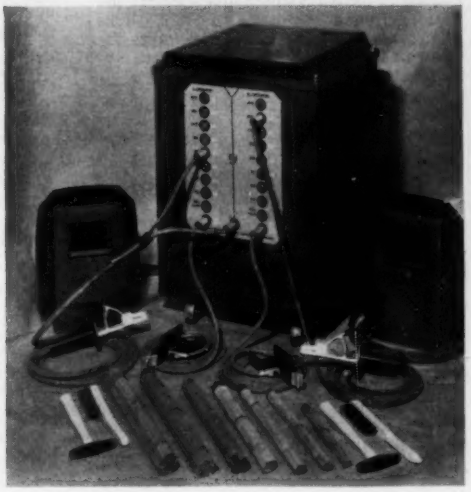
With the Weldcraft automatic system it is possible to braze at temperatures in the range 650° to 700°C.—about 100° lower than the normal temperature using manually applied flux. The fluxes that can be used with this method are restricted at present to the borax-based types, suitable for welding brass and for bronzewelding and brazing steel, malleable iron, copper, and copper alloys.

Arc welding transformers

Three new models have been added to the range of transformers made by Philips Electrical Ltd. The largest, type ES 1372, is a single operator machine supplying 350 amp, or it can supply 175 amp each to two operators. There are 64 tappings for varying the welding current.

In the medium range the general purpose type ES 1371 has a continuous maximum output of 175 amp.

The type ES 1370 machine is designed for use in the small workshop or garage and is especially suitable for welding sheet metal and, with a special 10 V tapping, for brazing thin sheet. It has an output of 65 amp.



Philips 350 amp welding transformer

Recording vibrations

The Askania Hand Vibrograph has recently been introduced by the Shandon Scientific Co. Ltd. to record on tape the amplitude and frequency of vibrations within the range 0–250 c.p.s. For measurements of vibrations above the natural frequency of the operator, about 5 c.p.s., the instrument is held firmly in the hand. With lower frequencies the instrument is used as a displacement meter and is clamped in position. With variations in the type of feeler magnifications of 1, 5, 20, and 50 can be obtained. A spring driven motor provides a running time of about 120 seconds.

Sintered High-density Material

Johnson Matthey & Co. Ltd., announce that they are now producing a machinable high-density material 'Mallory 1000' made by powder metallurgy from tungsten, nickel, and copper. It can be brazed either to itself or to other metals by means of Easyflo No. 3 brazing alloy used with Tenacity Flux 5A, or it can be copper brazed in a reducing atmosphere without flux.

Radiography of Thin Steel

A flexible step-wedge penetrameter for thin steel sections is being made by Inspection Equipment, of 19 Broad Court, Drury Lane, London W.C.2. It has five steps ranging from 0·0015 in. to 0·005 in., and is stated to give a more accurate record of penetrameter sensitivity on plate up to ¼ in. thick than the existing BWRA Size 1, and the DIN No. 1 penetrameters. A direct reading chart is supplied with the penetrameter.

Safety Lens Cleaning and Demisting

A cabinet for the quick and easy cleaning and demisting of eye safety lenses has been produced by Fleming Safety Equipment. It dispenses a fine spray of cleansing liquid and supplies a wiping tissue which will not damage plastic materials.

Flexible Cassettes

Inspection Equipment are also supplying flexible PVC cassettes with built-in lead rulers for positive location of defects. Films and screens are loaded into a black inner envelope and the whole pack slides into an outer casing. There is also a pocket at the back of the cassette to hold a backing lead sheet that can cover the entire film area.

Similar cassettes with snap fasteners for linking are also available for circumferential weld radiography.

New British Standards

Three new or revised British Standards have recently been issued.

BS.3065 "The rating of resistance welding equipment" formulates reasonable methods of comparing the performance of different makes of resistance welding equipment, based on the recommendations of ISO. Particular attention is given to the determination of temperature and the maximum permissible rise is tabulated.

BS.3067 "Dimensions of blanks for seam welding wheels" is intended to reduce the wide variety of blanks which manufacturers are at present obliged to stock.

BS.1724 "Bronze welding by gas" brings up to date the edition of 1951. It follows the basic style of other welding standards in specifying tests and inspection requirements, forms of joint, and details of filler materials and fluxes. The standard applies to the bronze welding of copper, mild steel, cast iron and malleable iron, and combinations of these metals.

In addition, BS.153 "Girder bridges", which was extensively revised in 1937 and for which Part 3a, "Loads" was re-issued in 1954, has now been re-grouped and issued as two separate publications. The first deals with materials, workmanship, protection against corrosion, weighing, shipping, and erection. It covers the newer high-tensile and notch ductile steels and nodular

cast iron, and deals with the flame cutting and preparation of edges and ends as well as sections on welding and metallization.

The second publication deals with stresses, design and construction, and will later incorporate the existing Part 3a on loads. It tabulates the factors to be considered in fatigue loading and specifies the basic permissible stresses in welds. This section also gives formulae and tables for the estimation of stresses in the structural members.

The prices of the foregoing Standards are: BS.3065—4*s.* 6*d.*; BS.3067—3*s.*; BS.1724—6*s.*; BS.153 (Pts. 1 & 2)—6*s.*; (Pts. 3b & 4)—15*s.* (Postage extra). They are obtainable from the Institution at 2 Park Street, London, W.1.

WELDING EXHIBITION

The Engineering, Marine, Welding, and Nuclear Energy Exhibition, organized by F. W. Bridges & Sons Ltd., is being held this month at Olympia, from **16th to 30th April.**

The Spring Meeting of the Institute of Welding has been arranged to coincide with the Exhibition, and the afternoon of Friday 24th has been left free for members to visit Olympia.

As in previous years, welding equipment manufacturers will be exhibiting as a group in the Empire Hall (Ground Floor) but there will be many examples of the applications of welding on the stands of other exhibitors.

Some of the newer developments in welding and allied equipment will be described in future issues of the *Journal*. But a few of the main features that will interest visitors concerned mainly with welding are briefly listed here under grouped headings.

Arc Welding

There is a considerable emphasis this year on automatic equipment.

Arc Manufacturing Co. Ltd.: Arc welding electrodes; contour following device for wire feed in gas shielded welding.

English Electric Co. Ltd.: Portable rectifiers; large range of single and multi-operator a.c. arc welding units; range of electrodes including iron powder types.

Lincoln Electric Co. Ltd.: Fused and unfused fluxes for submerged arc welding; twin-head tractor for submerged arc welding; fully automatic welding head on column/boom mounting; manual submerged arc unit with remote control; motor generators and standard products.

Murex Welding Processes Ltd.: Demonstrations of Muramatic equipment for submerged arc or open arc welding on a.c. or d.c.; fluxes and wires for automatic welding; generators, rectifiers and transformers; wide range of metal arc electrodes.

Portable Welders Ltd.: Fararc 200 portable arc welding unit.

Quasi-Arc Limited: Slag welding (vertical) unit; twin-fillet CO_2 welding machine; 'basic' automatic welding head assemblies; motor generator sets; plug-in rectifier; demonstrations of iron powder electrodes and standard products.

Rockweld Ltd.: Autopak unit with automatic arc voltage control; Comet CO_2 welding process using continuous composite wire.

Resistance Welding

In this field also there is evidence of increasing automation, especially in positioning of the items to be welded.

British Federal Welding Machine Co. Ltd.: Fully automatic drum forming and welding equipment.

Hirst Electronic Ltd.: Constant potential reactifier; specially designed welder for plastic coated steel sheet; current meter.

A.R.O. Machinery Co. Ltd., and Sciaky Electric Welding Machines Ltd.: Portable spot welding guns and special purpose welding machines.

Gas Welding and Cutting

British Oxygen Co. Ltd.: 1/10 scale model of computor controlled gas cutting machine; practical demonstrations of flame cutting and profiling, and the inert-gas welding processes.

Deloro Stellite Ltd.: Sprinkle fuse process of hardfacing.

Eutectic Welding Alloys Co. Ltd.: Low-temperature welding rods and fluxes.

Hancock & Co. (Engineers) Ltd.: Latest Hancomatic automatic flame cutting equipment. Hancoline automatic electronic oxygen profiling machine.

C. S. Milne & Co. Ltd.: Welding torches; cutting equipment; pipe bevelling.

Weldcraft Ltd.: Automatic flame fluxer; medium pressure acetylene generators.

Positioners and Manipulators

In addition to equipment shown by Lincoln Electric Co. Ltd. and Quasi-Arc Limited, there will be displays of special equipment on the stands of F. Bode & Co., Donald Ross & Partners, and Yates Plant Ltd.

Inspection and Testing

Industrial X-ray units will be shown by G. A. Harvey & Co. Ltd., Marconi Instruments Ltd.; ultrasonic inspection equipment by Metal and Pipeline Endurance Ltd.; Solus-Schall Ltd.; Ultrasonascope Co. Ltd.

Miscellaneous

A. P. V. Paramount will show Paralloy pipe fittings in stainless steel; W. C. Holmes & Co. Ltd. will show an inert-gas generator working from fuel gas or oil; Vacu-Blast will exhibit latest models of shot-blasting equipment.

STUB ENDS

▶ A new control system for automatic weighing has been developed by E.M.I. Electronics Ltd., which offers many features not previously available. Known as the EMIWAY system, this equipment can be fitted to most types of scales and makes possible the accurate control of any number of weighing operations. The weight of materials to be discharged from storage bins or hoppers can be set up on dials or programmed on punched cards or tape; automatic switching from fast to slow feed is provided. The system ensures accuracies in the region of 1 part in 1000 of the 360° of a scale dial movement.

▶ The Aveling-Barford Group of Companies have issued a new catalogue illustrating some of the earth-moving equipment manufactured by the Group on a world-wide basis.

▶ Metal and Pipeline Endurance Limited announce their appointment as official consultants and cathodic protection designers to the Government of Trinidad and Tobago. The work will cover all types of new underground structures and pipelines in those islands.

▶ The South Eastern area office of Birlec Ltd., manufacturers of heat-treatment furnaces, dryers and gas plants, has been transferred to Crown House, Aldwych, London, W.C.2 (telephone number: Temple Bar 8040). The South Eastern area office of Birlec-Efco (Melting) Ltd., has also been established at the same address.

▶ Matthew Hudson has joined the staff of Rockweld Ltd., as an automatic welding engineer. He will be responsible for preparing automatic welding schemes in the application of the Rockweld Autopak automatic welding equipment. Mr. Hudson, a qualified radiographer, has had wide experience of automatic welding, particularly in the construction of pressure vessels, as well as in shipbuilding and a broad range of engineering applications.

▶ The new plant of The Lincoln Electric Company (Aust) Pty. Ltd. was officially opened on 6th November 1958 at Padstow, New South Wales. It is essentially a single-storey structure 445 ft long and 300 ft wide, made up of welded steel frames with 60 ft H-section trusses and 35 ft jack trusses. The curtain walls, of composite aluminium and rock wool construction, are attached to the frames by arc welding and stud welds. The new building gives 50% more space for machine manufacture and 75% greater electrode manufacturing capacity over the old factory.

▶ A Data Sheet, TR issue 2, gives details of timers, delay switches, and sequence control panels made by Elcontrol Ltd. of Hitchin.

▶ The growing number of new photographic applications has made it necessary for Kodak Limited to expand their familiar Data Book of Applied Photography. A fifth volume is to be added, and conversion or renovation sets are being made available.

▶ A mobile showroom for the demonstration of welding and cutting equipment has been prepared by D. S. Baddeley Engineering Co. Ltd., to visit firms throughout Scotland.

▶ The 1959 Corrosion Exhibition, organized by 'Corrosion Technology', is to be held in the Royal Horticultural Society's New Hall, Westminster, on 27th–30th April.

▶ Hydraulic transmission units providing infinitely variable output speed in either direction, and with a wide range of applications in research laboratories and industrial concerns, are being produced by Vacuum Research (Cambridge) Ltd.

▶ A new service depot for Scotland, on the Nerston Industrial Estate at East Kilbride, has been opened by the Yale & Towne Manufacturing Co. (Tel.: East Kilbride 20241.)

▶ Representatives of the major oil companies and ancillary construction organizations recently visited the Sales and Technical Services Department of British Oxygen Gases Ltd. to view the latest welding techniques and equipment for oil pipelines and plants.

▶ A revised edition of "ICI Welding Rods and Brazing Materials" has recently been issued by the Metals Division of Imperial Chemical Industries Ltd. This gives comprehensive information, including tables, on the welding and brazing of such materials as copper, cupro-nickel alloys, brasses, Everdur, aluminium and phosphor bronzes, aluminium alloys, titanium, and the like.

▶ Electronic Machine Co. Ltd. have formed a Radiological Division, which is offering a complete radiation monitoring service to users of X-ray machines and other radioactive materials. An interesting and informative booklet has been prepared for the convenience of those wishing to investigate the possibility of employing this service. Copies can be obtained from Radiation Monitoring Service, 41 Lodge Road, West Croydon, Surrey.

DIARY

4th April—Manchester—Annual General Meeting and Film Show (College of Science & Technology).

6th–10th April—School of Welding Technology—Course on Welded Structures.

7th April—East Midlands—Annual General Meeting and Film Show (Welbeck Hotel, Nottingham, 7.15 p.m.)
North London (Slough Section)—*Recap for Welders* by F. E. Darling (Community Centre, Slough, 7.30 p.m.)

9th April—North Eastern (Tyneside)—*Welding of Small Ships* by E. D. Russell.

10th April—Liverpool—Entertain the Lecturers (St. George Restaurant).
Wolverhampton—Annual General Meeting (7.30 p.m.) and Film Show (8.0 p.m.)

13th April—Sheffield—Annual General Meeting and Film Show (Grand Hotel, Sheffield, 7.15 p.m.)

14th April—Liverpool—Annual General Meeting and Film Show (College of Technology, Byrom Street).
Leeds—Annual General Meeting (Gt. Northern Hotel, Leeds, 7.30 p.m.)
South Western—Annual General Meeting.

15th April—East of Scotland—Annual General Meeting (25 Charlotte Square).
West of Scotland—Annual General Meeting and Film Night.
South London (Medway Section)—Annual General Meeting (Sun Hotel, Chatham, 7.30 p.m.)
Wolverhampton—Annual General Meeting (Holly Bush Hotel, Wolverhampton, 7.30 p.m.)
North Eastern (Tees-side)—Annual General Meeting.

16th April—South London—*Welding in Nuclear Engineering* by H. E. Dixon. Followed by Annual General Meeting. (54 Princes Gate, S.W.7, 7.30 p.m.)

16th–30th April—Engineering, Marine, Welding, and Nuclear Energy Exhibition, Olympia.

17th April—Southern Counties—*The Welding of Copper Alloys* by C. A. Terry.

18th April—School of Welding Technology—Course on Health and Safety in Welding.

20th–24th April—Institute of Welding Spring Meeting (54 Princes Gate, S.W.7).

29th April—North London—Annual General Meeting and Film Show (54 Princes Gate, S.W.7).

1st May—Wolverhampton—14th Annual Dinner and Ladies Night (Wulfrun Hall, Wolverhampton).

APPOINTMENTS

Welding Engineer, aged 25–35, required by leading manufacturers of manual and automatic arc welding plant and electrodes for senior post in the Technical Sales Department. A wide knowledge of welding processes and a keen and enthusiastic interest in technical sales promotion is essential. Degree or equivalent qualification preferred. Box 229.

ENGLISH ELECTRIC

WELDING RESEARCH AND DEVELOPMENT LABORATORIES

Whetstone, Near Leicester

wish to engage a

WELDING ENGINEER

to undertake development work on new welding processes, and the application of traditional methods to materials used in the manufacture of steam, gas and water turbines and nuclear reactors.

Applicants should hold a degree, or its equivalent, and some experience in welding problems is desirable.

Please write giving details of education, qualifications and experience to Dept. C.P.S., Marconi House, 336/7 Strand, W.C.2. quoting reference WJ 1814M.

BRAINTREE COLLEGE OF FURTHER EDUCATION

Braintree, Essex

An **Assistant Grade A Teacher** for Welding and Sheet Metal Work will be required from 1st September 1959. Candidates must have good industrial and part-time or full-time teaching experience.

Salary: £475 × £25 to £900 with additions for degree (or equivalent), and approved training. Increments within scale for previous teaching service, approved industrial experience and War/National Service. Commencing salary could approach the maximum.

Details and forms (stamped, addressed foolscap envelope) from the Clerk to the Governors, Mid-Essex Technical College, Market Road, Chelmsford.

BRITISH WELDING RESEARCH ASSOCIATION

require a **Research Officer** and an **Experimental Officer** in the non-ferrous section of the Metallurgy Department at ABINGTON HALL, nr. CAMBRIDGE. Initially, work will be on problems in the inert gas shielded welding of aluminium alloys. The Research Officer, who should be a graduate in metallurgy or A.I.M., will be required to plan and carry out programmes and prepare reports under the direction of the head of the section. The Experimental Officer will collaborate with the Research Officer on practical aspects of the work, and for this purpose experience of inert gas shielded welding processes is essential.

Salary in the range £650–£1150. Superannuation scheme (F.S.S.U. for graduate or professionally qualified officers). Removal expenses paid.

Applications to the Secretary, B.W.R.A., 29 Park Crescent, London W.1.

Applications are invited for the appointment of a **Welding Engineer**. A degree in engineering or metallurgy, or equivalent qualifications are necessary, together with a sound knowledge of modern welding technology covering all classes and types of welding encountered in the structural engineering industry. Overall supervision of labour and negotiations with Trade Unions at shop floor level will be involved.

Starting salary will be in accordance with the applicant's age and experience. Applications, giving full details of experience, which will be treated in strict confidence, should be addressed to:

The Works Manager
The United Steel Structural Co. Ltd.
Frodingham Works
Scunthorpe, Lincs.

ANNOUNCEMENTS

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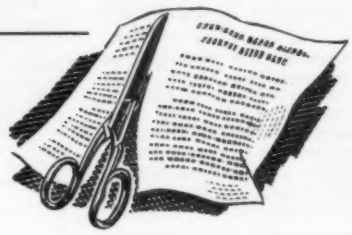
All other matters relating to advertisements for this section of the News should be addressed to the Executive Editor, 6 Ridge End, Hook Hill Lane, Woking, Surrey (Tel. Woking 2981).

Copy should be sent by 6th of each month for publication in the following month.

Current
WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications



CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

Australian Welding Journal, 1958, vol. 2, September

Equipment for hidden arc welding, L. H. Maclaine-Cross (13–17)

The practical approach to inert-gas welding of non-ferrous metals, J. Palmer (18–19)

Automatic welding on structural work—weld quality improved and output increased, M. Muras (20–21)

Deep penetration of the automatic welder used to advantage in production, A. J. Roe (22–23)

Australian Welding Journal, 1958, vol. 2, October

Steel fabrication for profit, R. K. Pinna (20–27)

The production heat sealing or welding of plastic, H. Rodin (28–32)

An application of CO_2 shielded-arc welding, I. McBryde and J. Wardrop (44–49)

The manufacture of welded steel tube, J. Gosse (50–55)

Recent developments in manual arc welding, D. C. Cooke (56–60)

Australian Welding Journal, 1958, vol. 2, November

Mild steel electrodes code classification: Table of comparisons showing three classification listings to (a) Australian Standard B130:1955, (b) British Standard 1719:1951, (c) AWS-ASTM (11)

Quarrying costs cut by hardfacing, C. V. Whitehouse (12–18)

The scope of hardfacing, R. S. Cox (21–27)

Canadian Welder, 1958, vol. 49, October

Semi-automatic hardfacing (10–11)

Structural welding: inter-relation between materials, details of design, construction procedures, and service conditions, part 2, Dr. LaMotte Grover (12–17)

Soldering stainless steel (18–19)

Automatic arc welding machine (20–21)

Canadian Welder, 1958, vol. 49, November

Stud welding applied to vibrating wire strain gauges, J. C. Chapman (12–13)

Machine for powder-cutting stainless steel (14, 16)

Automatic welding speeds axle case production (18–19)

UHF resistance welding (24)

Journal of the Japan Welding Society, 1958, vol. 27, November

A review of studies on hot cracking of austenitic stainless steels for high-temperature and high-pressure service, J. Omuri and H. Maruoka (5–12)

New shipbuilding method for shifting large stern block, T. Yoshida (12–16)

Arc phenomenon of multiple electrode submerged-arc welding, H. Kihara, K. Masubuchi, Y. Ogura, O. Takagi, and M. Hamazaki (17–22)

Cooling curve, microstructure and hardness in welding heat-affected zone of high-tensile steel (Report 4), H. Sekiguchi and M. Inagak (23–29)

Studies of non-metallic inclusions in basic weld metal (Report 1), H. Sakaki (30–34)

Welding of rail joints by manual arc method (Report 2), S. Morita, T. Ito, and T. Yonei (35–40)

Some experiments on the Murex hot-crack testing machine, K. Ishizaki and T. Nishi (41–46)

On the cracking of metal in the constrained welding of mild steel, S. Morita, S. Goda, J. Okamoto, and M. Kumagai (47–49)

Journal of the Japan Welding Society, 1958, vol. 27, December

A review of studies on hot cracking of austenitic stainless steels for high temperature and high pressure service, report 2, J. Omori and H. Maruoka (2–12)

A study of arc welding apparatus with superposed high frequency pulses, I. Ukita, T. Mine, S. Miyamoto and S. Kokawa (13–17)

Welding conditions of steels and cooling time near the fusion line, report 1, M. Inagaki (18–24)

A metallurgical study on the weld heat affected zone in steels with a reproducing apparatus for weld thermal cycles, report 4, H. Suzuki and H. Tamura (25–31)

Cooling curve, microstructure and hardness in welding heat-affected zone of high tensile steel, report 5, H. Sekiguchi, M. Inagaki and M. Miyata (32–38)

Studies of non-metallic inclusions in basic weld metal, report 2–3, H. Sakaki (39–45)

Study on welding of low-alloy high strength steel, report 2, Y. Ito, Y. Araki and K. Nikuma (46–50)

La Pratique du Soudage (Belgium), 1959, vol. 13, January

Some applications of welding in the permanent way of railways and tramways, Vandenberghen (1–9)

Welding of resinous materials; polymers (9–13)

Przeglad Spawalnictwa (Poland), 1958, no. 11, November

New electrodes for welding thick copper plates, J. Wegrzen

Standardization of weldment evaluation on the basis of radiographic inspection, M. Radwen and A. Fabieszewksi

Flux cored wire for automatic submerged arc surfacing, J. Brozda

Influence of radiographic inspection on welding work quality, M. Mendrek

Przeglad Spawalnictwa (Poland), 1958, December

Fatigue tests of welded structural elements, T. Robakowski

Application of metal spraying in stressed bolt joints, J. Kasinski and T. Nawrot

Transformer welding machines of Polish make, S. Sokolowski

Przeglad Spawalnictwa (Poland), 1959, No. 1, January

Problems of technical gas production in Poland, R. Sznerr

Arc welding of cast iron, J. Wegrzyn

Welding of steam turbines construction, R. Pasierb

Revue de la Soudure Lastijdschrift (Belgium), 1958, vol. 14, December

The present state of the brittle fracture problem, G. M. Boyd (175–187)

Soviet work in the field of fracture of metals, J.-B. Friedmann (188–200)

The effect of storage time on the presence of hydrogen and the mechanical properties of arc welds with covered electrodes, W. Hummitzsch (213–222)

Schweissen und Schneiden (Germany), 1958, vol. 10, November

Bonding technique for heavy and non-metallic materials, H. Winter and H. Meckelburg (423–433)

Application of welding to harbour structures with particular reference to the structures in the Port of Hamburg, O. Lütgens (434–438)

Limitations in the evaluation of gamma radiography used for examining circumferential pipe welds in accordance with DIN 54111 Welding of wheel rims for railway rolling stock by means of inert-gas arc welding, H. Becker (442–444)

Schweissen und Schneiden (Germany), 1958, vol. 10, December

Modern chemistry and its effects, A. Steinhofer (455–463)

Optimum intensification and fault definition through the use of suitable lead screens for gamma radiographs with Ir 192 and Cs 137, W. H. Papke (463–466)

Explosion-protected electrical equipment in acetylene plants, G. Engel (467–471)

The use of protective gas as protection against oxidation during the welding of alloy steels, J. Wingerath and K. Boeckhaus (471–475)

Schweissen und Schneiden (Germany), 1959, vol. 11, January

The welding engineer and the qualified welding engineer, H. Koch (4–7)

Fatigue strength of flame cut steel specimens repaired by welding, A. Matting, H. Wolf and H.-d. Steffens (8–16)

The measurement of welding currents, E. Rohloff (17–22)

Increasing the economic efficiency of submerged arc welding through the use of the open joint welding technique, W. Schatz (23–29)

La Soudure Electrique (Belgium), 1958, No. 3

Resistance welding of high tensile carbon steels and low alloy steels (3–16)

Course on resistance welding, E. J. Belotte and G. E. Lheureux (17–23)

Essays on metallurgical weldability, J. Cabelka (24–32)

South African Institution of Welding, Bulletin, 1958, no. 68, November

Welding training (2–6)

Metal or alloy? Vanadium (6–7)

Rectifiers for electric welding (8–9)

Welding Engineer (U.S.A.), 1958, vol. 43, November

The effect of arsenic on mechanical properties of welds in mild steel, D. Canonico and H. Schwartzbart (32–35)

The fundamentals of welding engineering, part 3, T. B. Jefferson (36–37)

Stress relief by-passes on ship, G. A. Hughes (41–42)

The dangers of carbon tetrachloride (60)

Welding Engineer (U.S.A.), 1958, vol. 43, December

Tooling and welding team-up for economy—on specialized pressure vessels, G. Garfield (40–42)

Contour welding with a magnetic-tape tracer system (50–51)

Resistance welds will improve if you know your metals and electrodes, L. F. Spencer (54, 56–59)

Welding Engineer (U.S.A.), 1959, vol. 44, January

Kaiser plant welds legs for giant offshore tower (36–37)

Producer gives instruction for welding moly, R. R. Freeman and J. Z. Briggs (38–41)

"Flexible automation" on refrigerator welding lines (42–43)

Typewriter parts are projection welded (44–45)

Loading crane vital cog in shipping firm's new time-saving system (46)

Fine mesh screen can now be Tig welded with a new set-up (50)

Ultrasonic welding comes of age (52)

Fire prevention and protection in welding and cutting operations, R. Cholin (57–58)

Welding and Metal Fabrication, 1958, vol. 26, November

Jet engine testing plant: welded fabrication of the new

Rolls-Royce installation, T. S. Macneish and D. W. Wilson (388–396)

Practical aspects of automatic welding—2, J. A. Lucey (397–402)

Powder-cutting of stainless steel, A. L. Chappell (403–404)

Metal working processes and equipment—1, A. G. Thompson (405–411)

Factors influencing the specification of resistance welding plant, I. Jones (412–415)

Welding and Metal Fabrication, 1958, vol. 27, January

Mass production of all-welded rail wagons (2–4)

Hardfacing by rod and metal powders; A survey of old and new methods of hardfacing, E. Wallace (5–13)

Aluminium bridge construction (14–16)

Contraction in a welded propeller shaft, D. Birchon (17–21)

The Atomium; An account of its design and its construction problems (22–25)

Metal-working processes and equipment—3, A. G. Thompson (26–30)

Torch brazing and hard soldering pure titanium in air, R. C. Shelley (31–32)

Fabrication of aluminium pressure vessels, J. F. Lancaster (33–34)

Welding and Metal Fabrication, 1959, vol. 27, February

Inert-gas metal-arc welding aluminium using fine wire electrodes J. E. Tomlinson and A. J. King (42–50)

A fabricated 7,000 ton electro-magnet, T. J. Palmer (51–53)

The Colmonoy sprayweld process and its applications, W. J. Burling Smith (54–60)

Some facts about iron powder electrodes, A. B. Fieldhouse (61–70)

Metal-working processes and equipment - 4, A. G. Thompson (71–73)

The Atomium - 2 (74–75)

Welding News (Australia), 1958, Folio 96, October

Hardfacing against high temperature corrosion (10)

Powder cutting (15)

The Comet is a multi-purpose blowpipe (16–19)

Flame hardening railway wheels (20)

Welding Production (U.S.S.R.), 1958, November

Electro-slag welding by means of strip electrodes, B. A. Koch (3–7)

Method of evaluation of notch-ductility and sensitivity to low-temperature practice of manual and semi-automatic welds, M. M. Kraitchik and K. V. Pashkov (7–10)

Effect of low frequency vibration on weld metal crystallization and properties, V. L. Russo and P. N. Efimov (10–12)

Study of pipe pressure welding process, V. D. Taran and others (12–14)

Effect of twin-arc welding parameters on fusing of electrodes and parent metal, V. N. Sherstjuk (15–16)

Fusion spot welding of moulding chain links in a carbon dioxide atmosphere, L. K. Ershov and others (17–19)

Automatic overhead submerged arc welding of pipes, A. S. Falkevitch (19–23)

Selection of spot welding parameters for high-strength aluminium alloys, B. D. Orlov and P. L. Tchuloshnikov (23–26)

Use of gas welding for repairs of cast-iron components, K. P. Voshtchanov (26–29)

Ultrasonic inspection of welds in welded-cast structures, I. N. Ermolov (29–32)

Technical and economical effect of air-arc cutting, I. S. Shapiro (33–34)

Welding Production (U.S.S.R.), 1959, No. 1, January

Fatigue strength of electroslag welds in large steel castings, I. V. Kudriavstsev and N. E. Naumtchenkov (4–9)

Properties of the heat affected zone in welds of B.95 alloy, V. L. Russo and I. P. Prosiankin (9–12)

Properties of austenite weld type at high temperatures, V. A. Toropov (12–16)

Calculation of coatings for arc welding electrodes, A. A. Erokhin (16–20)

Radiographic study of the distribution of Niobium in stainless steel, L. S. Livshits and L. P. Bakhrakh (20–22)

Optimum conditions for oxygen cutting of steels, V. S. Iljinsky (22–24)

Study on the thermal processes in gas pressure welding of rods, M. S. Nikitin (24–27)

Butt welding by high voltage capacitator discharge, P. I. Evtifeev (28–31)

Investigation of spot and seam welding of steel, A. F. Malukov (31–35)

Arc welding of copper-nickel alloy pipes, B. I. Smirnov (35–37)

New universal automatic welder, A. F. Kozhaiev (37–40)

Cast-welded stern frame for atomic ice-breaker, P. A. Orekhov (40–41)

Welding Journal (U.S.A.), 1958, vol. 37, November

The welding of some non-ferrous and ferrous tubes to tube sheets, R. W. Beenett (1071–1080)

Welding alloy steels under bonded fluxes, H. C. Campbell and W. C. Johnson (1081–1089)

Handling and use of acetylene at elevated temperatures, H. Beller (1090–1096)

Welding products play important roles in development and production of transistors, R. Ingraham and J. F. Buerkell (1097–1098)

Three times faster with magnetic-flux gas-shielded arc welding, H. C. Hogue (1099)

Effects of chemical composition on cracking resistance of high-strength-steel weld metals, R. P. Sopher (481s–492s)

Metallurgy of bonding in brazed joints. Pt. 1—Base metal-filler interaction, excluding compound formation, N. Bredzs and H. Schwartzbart (493s–498s)

Development of methods for end capping PWR fuel elements, J. J. Vagi and D. C. Martin (499s–506s)

Welding of galvanized steels, I. L. Stern and H. Nagler (507s–514s)

Design of a thin-walled cylindrical pressure vessel considering plasticity, J. Marin and M. G. Sharma (515s–519s)

Mechanical tests of spot welds, E. C. Hartmann (520s–523s)

Effect of pressure on the diffusion of zinc in alpha brass, A. G. Guy and C. Spinelli (524s–526s)

Welding Journal (U.S.A.), 1958, vol. 37, December

Controlled-atmosphere arc welding, N E. Weare and R. E. Monroe (1169–1175)

Use of radio-isotopes in filler metal for non-destructive inspection, P. T. Barnes and G. L. Locher (1176–1181)

A simplified approach to calculating design stresses, O. W. Blodgett (1182–1192)

The value of nitrogen as a weld backing gas, R. V. Anderson (1193–1195)

The birth of goliaths; huge coal trucks will haul 60 tons a trip, C Mitchell and H. R. Miller (1196–1197)

Gas-shielded metal-arc welding aids resurfacing of copper electrode holders (1199)

Joining of Zircaloy to stainless steel, J. B. McAndrew, R. Necheles and H. Schwartzbart (529s–534s)

Further evaluation of Ni-Cr-B and Au-18Ni brazing alloys, W. H. Chang (535s–542s)

Effects of preheating, thermal stress relief and electrode type on notch toughness, L. J. McGeady (543s–553s)

Postheat treating weldments with an exothermic material, M. F. Sheely and B. L. Lacey (554s–557s)

A survey of the bonding of cermets to metals, G R. van Houten (558s–569s)

Plastic design of thick-walled pressure vessels, J. Marin and F. P. J. Rimrott (570s–576s)

Index to the Welding Journal, vol. 37, 1958

Welding Journal (U.S.A.), 1958, vol. 38, January

Submerged-arc applications in the fabrication of railroad-car components, C. A. Zwissler and R. Z. Hay (13–19)

Alloy welding fluxes for low-alloy steels, stainless steels and hard surfacing, R. A. Wilson (20–27)

Inert-gas consumable-electrode welding of thin material, T. McElrath (28–33)

Joining aluminium with high-zinc solders by abrasion soldering, O. R. Singleton (34–36)

The weld heat-affected zone, E. F. Nippes (1s–18s)

Welding stainless steel to carbon or low-alloy steel, J. J. B. Rutherford (19s–26s)

Carbon-dioxide-shielded metal-arc welding of carbon-steel plate, R. J. Keller (27s–38s)

Pressure equipment for low-temperature service, C. R. Soderberg (39s–44s)

Effects of residual stress on fatigue strength, D. S. Dugdale (45s–48s)

Welding Research Abroad (U.S.A.), 1958, vol. 4, December

Determination of total hydrogen contents of weld metal: Commission II - Arc welding, Sub-commission A. 11W/11S-8-58 (ex doc. II-6-57) (2–8)

Annual report of Commission IV "Documentation", Essen Assembly, 1–5 July 1957. (Doc. IV-74-58) (9–10)

I.I.W. Co-operative work on brittle fracture. IIW/IIS-3-58 (ex doc. IX-198-57) (11–12)

Method for measuring tri-axial residual stresses, R. Gunnert. (doc. X-184-57) (17–25)

Investigation of damaged parts of vibrator units: Commission XIII - "Fatigue testing". IIW/IIS-4-58 (ex doc. Comm. XIII-1955) (26–31)

The weldability of steels for engineering construction, K. L. Zeyen (abstracted from Bauingenieur, 32, 209–217, 420–428 by G. E. Claussen (32–44)

The metallurgical weldability test, J. Cabelka (abstract of "L'essai de soudabilite metallurgique" by G. E. Claussen) (45–48)

Welding Research Abroad (U.S.A.), 1958, vol. 5, January

Researches on weldable high strength steels, H. Kihara, H. Suzuki and H. Tamura, Chapter 3: Notch toughness (2–43)

Report on recent tests on a welded connection: experiments on end connections of I beams subjected to shear, bending and combination of shear and bending, F. K. Ligtenberg. IIW/IIS doc. XV-69-58 (44–48)

Fatigue tests on butt joints welded automatically by the Unionmelt and Fusarc processes, Z. G. Martin and F. C. Falco. IIW/IIS doc. XIII-161-58. (49–58)

Zeitschrift für Schweisstechnik-Journal de la Soudure (Switzerland), 1959, vol. 49, January

Welding cast austenitic steel without cracking, W. A. Stauffer and A. Keller (2–6)

New welding processes for use in atomic energy work, C. G. Keel (7–9)

Today the use of acetylene with high pressure offers a high degree of safety, F. Loos (9–14)

Electro-slag welding, C. G. Keel (15–17)

Experiences with welded railway bridges, R. Becker (17–22)

Zvaranie (Czechoslovakia), 1958, vol. 7, November

The eighth International Welding Congress, O. Izdinsky (322–325)

The measuring of internal stresses caused by local heating, T. Zrna (325–331)

Upsetting on upsetting machines by electric resistance heating, M. Lipa (331–336)

Economy in resistance welding, Z. Drab (336–340)

New methods of welding in the construction of steam generators and pressure vessels, J. Kurka (341–342)

The electrical engineer addresses the welders, O. Zakavec (343–346)

Technology of gear wheel repairs by surfacing them with the aid of copper shaping moulds (346)

Zvaranie (Czechoslovakia), 1958, vol. 7, December

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Contribution to the welding of vacuum vessels, A. Kloss (356–362)

Engine-room section in the building of river ships and the welding of steel reinforcements to the bottom cover sheet, O. Izdinsky (363–368)

Automatic stud welding under flux, M. Zaruba (368–373)

Technology of gear-wheel repairs by surfacing them with the aid of Cu shaping-moulds (conclusion), O. Zakavec (373–378)

Other Journals

CO_2 welder makes casting repair easier, J. J. Chyle (*Steel* (U.S.A.), 1958, vol. 143, November 17, pp. 110–112)

Magnetic-flux gas-shielded arc welding, J. E. Dato (*Engineers' Digest*, 1958, vol. 19, November, pp. 491–492)

Titanium fabrication advanced by spotwelding (*Steel* (U.S.A.), 1958, vol. 143, November 24, p. 117)

Operation of the ignitron, R. B. Robins (*New Zealand Engineering*, 1958, vol. 13, October 13, pp. 381–385)

Resistance casting (*Aircraft Production*, 1958, vol. 20, December, p. 463)

An apparatus for testing the solderability of wire, J. A. ten Duis (*Philips Technical Review* (The Netherlands), 1958–59, vol. 20, December, pp. 158–161)

Selecting solders for low temperature service, A. B. Kaufman (*Materials in Design Engineering*, 1958, vol. 8, November, pp. 114–115)

Dip brazing magnesium (*Metal Industry*, 1958, vol. 93, December 19, pp. 513–514)

Metal spraying: effect of a molybdenum deposit on adhesion and on fatigue of ferritic steels, D. Birchon (*Metallurgia*, 1958, vol. 58, December, pp. 273–285)

Contraction stresses in sprayed metal deposits, W. E. Stanton (*Metal Industry*, 1958, vol. 93, December 19, pp. 509–511)

Spayed electrolytic zinc coatings, R. Bourcelot (*Metal Industry*, 1958, vol. 93, November 28, pp. 453–454)

Non-destructive testing. Part IV—Development of radiographic methods of inspection: examination of aircraft structures (*Aircraft Production*, 1958, vol. 20, December, pp. 464–482)

Magnetic flaw detection, A. G. Gardner (*Metallurgia*, 1958, vol. 58, December, pp. 309–312, 308)

Recent progress in non-destructive testing, A. C. Rankin (*Engineering Materials and Design*, 1959, vol. 2, January, pp. 19–23)

Automatic flaw-detection; inspection equipment for gas-turbine rotor-disc billets (*Aircraft Production*, 1959, vol. 21, January, pp. 2–5)

Fabricator sets up "Countdown" to insure top-quality welds, R. F. Gurnea (*The Iron Age* (U.S.A.), 1958, vol. 182, November 27, pp. 65–68)

Employment of X-rays in welding (*Arco e Gas* (Italy), 1958, vol. 8, July to December, pp. 10–14)

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